ECONOMIC GEOLOGY

WITH WHICH IS INCORPORATED

THE AMERICAN GEOLOGIST

VOL. VI APRIL–MAY, 1911 No. 3

THE RÔLE OF HYDROLYSIS IN GEOLOGICAL CHEMISTRY.[1]

ROGER C. WELLS.

Since geologists can hardly be expected to keep in touch with special questions in chemistry it is natural that they have taken very little notice of the phenomena of hydrolysis, if indeed they realize what is meant by the term. Physical chemistry with its theories of solution and ionization has made such rapid progress that it may be advisable occasionally to translate some of its conclusions into terms which may be understood and applied by geologists.

Hydrolysis concerns aqueous solutions and signifies a reaction of a salt with water so that instead of the salt, *acid* and *base* are produced. Thus, as an extreme illustration,

$$MgCl_2 + 2H_2O = Mg(OH)_2 + 2HCl,$$

a reaction produced by evaporating a solution of magnesium chloride. Here the reaction may be carried to practical completion because of the volatility of hydrochloric acid. A hydrolytic reaction may likewise be caused by the removal of one of the possible products as an insoluble precipitate, thus

$$FeCl_3 + 3H_2O = Fe(OH)_3 + 3HCl,$$

[1] Published by permission of the director of the U. S. Geological Survey.

although in this case it is necessary to remove the excess of hydrochloric acid by neutralization, or in some other way, at the same time that the ferric hydroxide is precipitated in order to prevent the reverse action.

As thus explained, not much physical chemistry is required for these reactions, but other cases demand a somewhat larger theory of solution and it is necessary to take ionization into account. In accordance with the theory of electrolytic dissociation or ionization of substances in solution a solution of a salt in water contains not only molecules of the undissociated salt but also its simple ions and any other ions capable of being formed from the constituents in the solution including the water itself. The properties of a solution are the properties of its predominating constituents. Thus all solutions of acids are characterized by ionized hydrogen, and bases by hydroxyl ion. No other explanation of acidity and its opposite quality, alkalinity, fits all the facts as well as this one. "Strong" acids and bases are those having chiefly ions and few molecules; "weak" ones those having chiefly molecules and few ions. These various degrees of ionization are counted empirical physical properties of the various acids and bases.

When a salt is dissolved in water and with the water yields a strong acid and a weak base, there are hydrogen ions in plenty but only molecules of the base so that the solution is acid, as with the chlorides of aluminum, copper and zinc. Conversely, if the salt yields a strong base and weak acid the solution will be alkaline, as with potassium or sodium borate, carbonate or cyanide. The acids in order of strength are: hydrochloric, nitric, sulphuric, oxalic, tartaric, acetic, carbonic, hydrosulphuric and boric. Silicic acid is extremely weak, but its exact position in the series has not been determined. For the bases, it has been shown that the hydroxides of the alkali and alkaline earth metals are equally strong, followed by various amines, ammonium hydroxide and aniline.

Mine waters containing metalic salts will, for these reasons, usually "react" acid, but waters containing sodium carbonate

will react alkaline. The hydrolysis is not necessarily accompanied by precipitation.

The degree of hydrolysis of a given salt increases with dilution or with a rise of temperature. The same factors act similarly upon the *rate* of hydrolysis where the reaction proceeds slowly enough to be measurable, as I have shown in the case of ferric sulphate solutions, where the hydrolysis is accompanied by the formation and precipitation of a "basic salt."[1] The rate of hydrolysis in this case was determined by measuring the electrical conductivity of solutions of various dilutions at several temperatures. The increase of conductivity corresponds to the production of sulphuric acid in the solution. The relative rates of change for several cases are shown in the following table:

Dilution, liters containing one gram-equivalent of $Fe_2(SO_4)_3$.	Temp.	Initial equivalent conductivity.	Equivalent conductivity after one hour.
300	0°C.	78	86
600	0	96	111
61.1	30	95	102
101	30	110	141
121	30	118	152
151	30	128	180
201	30	142	202
300	30	165	258

The protean shapes taken by iron oxide formations probably illustrate the influence of slight variations in acidity or alkalinity during their deposition. I have not been able to detect any hydrolysis with *ferrous* sulphate solutions occurring slowly enough to follow experimentally.

In most metallic salt solutions showing acid reaction the hydrolysis does not go far before an equilibrium is attained at ordinary temperatures. With sodium carbonate the degree of hydrolysis at 24.1° C. has been determined for several concentrations, the degree expressing the per cent. of total sodium which may be thought of as sodium hydroxide.

Mol. Na_2CO_3/liter	0.1900	0.0940	0.0477	0.0238
Per cent. hydrolysis	2.12	3.17	4.87	7.10[2]

[1] *Jour. Am. Chem. Soc.*, 31, 1028, 1909.

[2] Shields, *Z. physik. Chem.*, 12, 167, 1893.

Since CO_2 escapes from a sodium carbonate solution upon boiling the hydrolysis may be carried further, as follows, starting with a normal solution.[1]

Time of boiling	1.25	3.5	6.0	8.5	23.3	38 hours.
NaOH formed	3.3	5.4	7.3	8.6	13.0	17.2 per cent.

The geologic application of these facts is that solutions are not always what they seem. A sodium carbonate solution really contains sodium hydroxide and may be expected to have the geologic action of sodium hydroxide, as in dissolving silica or precipitating hydroxides where the hydroxides are more insoluble than carbonates.

Solutions of all carbonates are more or less hydrolyzed, not excepting solutions of the insoluble carbonates.

Considering only ions the reactions for hydrolysis would be

$$CO_3'' + H_2O = HCO_3' + OH'$$
$$HCO_3' + H_2O = H_2CO_3 + OH'.$$

The first reaction occurs chiefly with normal carbonates, the second to a slight extent both with normal and acid carbonates. In accordance with these views a sodium bicarbonate solution contains (1) ionized sodium Na^+, (2) bicarbonate ion, HCO_3', (3) $NaHCO_3$ molecules, (4) hydroxyl ion, OH', (5) carbonic acid, H_2CO_3, (6) free carbon dioxide, CO_2, (7) a vanishingly small quantity of hydrogen ion, H^+, to correspond with the dissociation of the water. Other salt solutions may be worked out similarly. These cases show that the simple equations often given by geologists to account for observed occurrences do well if they explain the principal mechanism of the changes considered.

In the ionization of univalent-bivalent acids and bases the primary ionization is into two univalent ions.

[1] Küster u. Grüters, *Ber.*, 36, 748, 1903.

	H_2SO_4	yields	$H^{\cdot}$	and HSO_4'
	H_2S	yields	$H^{\cdot}$	and SH'
	H_2F_2	yields	$H^{\cdot}$	and HF_2'
	$Ca(OH)_2$	yields	$CaOH^{\cdot}$	and OH'
also	$NaHCO_3$	yields	$Na^{\cdot}$	and HCO_3'

It is only in the ionization of *salts* that the simpler bivalent or polivalent radicles occur to a large extent.

If hydroxide ion is the chief agent in attacking a rock it is evident that sodium carbonate would act more vigorously than sodium bicarbonate, the latter more vigorously than water and the last more vigorously than acid solutions. Similar deductions would follow from a consideration of the hydrolysis of silicates and borates.

Since all the hydrolytic reactions with which we are acquainted proceed further at higher temperatures than at ordinary, it is obvious that in geologic reactions where water is present at any considerable elevation of temperature hydrolysis plays a very important rôle. Water attains its critical temperature at 365° C. and its critical pressure at 195 atmospheres, which corresponds to about 2,500 feet in depth in a rock as dense as 2.5.

High temperatures correspond to certain general chemical conditions. In the first place substances tend to exist in simpler compounds than at lower temperatures. Many gases are partially dissociated. Fused substances often exist as mere mixtures of their constituents in indefinite proportion. Complex molecules are broken down. Hydrates or solvates, solid at lower temperatures, are decomposed above their "transition temperature" into water or solvent and lower hydrates or anhydrous salts, the water of course forming saturated solutions of the salts present.

The phenomena of ionization and hydrolysis change somewhat as the temperature rises.

Concerning the extent of ionization in aqueous salt solutions, the researches of A. A. Noyes and his co-workers have proved

that ionization in dilute solutions decreases steadily in all cases with rising temperature, the decrease being more rapid the higher the temperature and the greater the valence-product of the ions of the salt.[1] But the decrease in the reactivity which might be expected on this account is more than made up for by the higher rates of diffusion and the chemical activity of water at higher temperatures.

In contrast to the decrease of ionization of salts with rising temperature water itself increases its ionization and becomes at high temperatures a very active chemical agent. The increase in its ionization is shown in the following table:[2]

Temp.	Ionization $C_H \times 10^7$.
0°	0.30
18	0.68
25	0.91
100	6.9
156	14.9
218	21.5
306	13.0

It is seen that the ionization increases rapidly from ordinary temperatures up to about 250° attaining a maximum somewhere between 250° and 275°. If the water were pure and the ionization of hydroxyl into O″ and H′ is neglected the above concentrations of hydrogen-ion would also be those of hydroxyl-ion. In salt solutions, however, as has been stated, the hydroxides and acids are rarely of equal "strength," the hydrogen-ion-concentration exceeds or is less than the hydroxyl-ion-concentration, as the case may be, giving alkaline or acid reaction. When it is remembered that the ionization of weak acids and bases decreases with rise of temperature and that this acts in the same direction in increasing the hydrolysis of salts as the ionization of water shown above it will be evident that salts must hydrolyze much further at high temperatures. The result would appear to be in general a marked tendency towards the separation of the

[1] *J. Am. Chem. Soc.*, 31, 1009.
[2] Noyes, Carnegie Inst., Pub. 63, 346.

oxides of the metals, particularly if there were at the same time any chance for the escape of volatile products. At these temperatures very slight changes in acidity and alkalinity would undoubtedly condition important changes in crystallization and so on. This may be the key to the action of traces of water as a "mineralizer."

A THEORY FOR THE ORIGIN OF GRAPHITE AS EXEMPLIFIED IN THE GRAPHITE DEPOSIT NEAR DILLON, MONTANA.[1]

ALEXANDER N. WINCHELL.

Imports of graphite into the United States regularly and largely exceed the domestic production, even when the total production of both natural and artificial graphite is considered. It is evident, therefore, that a careful study and a wider knowledge of all natural supplies of graphite are desirable.

In the southern part of the Dillon quadrangle, Montana, about sixty miles nearly due south of Butte, deposits of high-grade flake or crystalline graphite occur. These deposits are chiefly on the ridge between Van Camp Creek and Timber Gulch Creek near the southwest end of the Ruby Range of mountains and are reached from Dillon by a drive of about fifteen miles to the southeast over a good mountain road.

The rocks exposed in the Ruby Range are chiefly the thick limestone series of the Paleozoic of Montana, which have in the southwest end of the range been repeatedly faulted, perhaps at the time when they were arched and folded into mountains. At the mouth of Van Camp Canyon, limestone, apparently of lower Paleozoic age, dips to the northwest; but farther up the canyon it appears that this limestone is underlain by quartzite (the Flathead quartzite?), which overlies quartz schists and slates, apparently pre-Cambrian in age. By faulting this series is repeated so as to outcrop at least three times within about two miles. Igneous rocks are uncommon, but one dike of a basic type was observed.

At the graphite property, at an elevation of 7,500 to 8,000 feet above sea level, and about 2,500 feet above Dillon, the average

[1] Published by permission of the director of the U. S. Geological Survey.

strike is about N. 70° E. and the average dip is about 45° to the north-northwest.

The graphite presents the remarkable condition of occurring in several different ways in this single property. The first mode of occurrence observed is as seams in sedimentary rocks. The seams are mostly narrow and rather persistent, ordinarily not more than an inch or two in thickness and strictly parallel with the bedding. On the Faithful claim they occur in marbleized limestone, on the Lucky Boy in the underlying quartz schists, mica schist, and garnet schist. At another outcrop on this claim the graphite occurs in somewhat irregular seams on both sides of a graphic-granite intrusion, lying apparently as a sill in rather massive garnetiferous quartz schist. A basic dike, 30 to 40 feet wide, cuts across the formations a short distance to the west, and faults all of them.

West of this dike the graphite is chiefly in veins and faults not parallel with the bedding, which here strikes about north with a dip at about 50° to the west, while the graphite occurs in a fault vein striking N. 70° E. and dipping about 60° N.N.E. Graphite also occurs in veins and faults in several other positions, and some of the veins containing graphite are cut by faults. An adit tunnel opening some of this ground discloses graphite in irregular bunches, pockets, stringers, and veins, having no relation to bedding, but similar to the mode of deposition of vein material in zones where rocks have yielded to stresses, not by clean fracturing, but by irregular shearing. In such places, irregularly lenticular masses may reach 6 to 8 inches in thickness, and 2 to 4 feet in diameter. At the time the property was visited in 1910, the sheared rocks had only recently been penetrated. The shearing affects a thickness, at least locally, of some 3 to 5 feet. Its continuity as a well-defined zone is not yet established.

At another outcrop the graphite occurs in intimate association with garnet. At times it completely surrounds large crystals of garnet; more commonly a crystal of garnet is surrounded by quartz which in turn is largely surrounded by graphite. Again, graphite occurs in seams in garnet, or garnet, quartz and graphite

occur quite intimately mixed. Schists form the country rock in these cases.

At another outcrop graphite occurs intimately intergrown with quartz, feldspar and mica, making a sort of graphitic gneiss. Again, the mica disappears, and the graphite becomes more abundant. In this case the graphite may be one third of the rock, and it serves as a matrix in which lie the feldspar anhedra, with more or less associated quartz. Such graphitic gneiss is not known to be abundant.

Near the east end of the property graphite occurs above a fault containing pegmatite in a decayed quartz feldspar rock resembling a pegmatite. This rock lies in layers more or less parallel with the pegmatite, which intrudes the limestone in sills. The graphite separates the layers and sometimes cuts across them. The graphitic material here is usually narrow; it rarely exceeds an inch or two in thickness.

ORIGIN OF THE GRAPHITE.

Smith[1] has called attention to two graphite properties in Maine which illustrate different modes of origin of the mineral. Still more recently, Hayes and Phalen[2] have described an occurrence of graphite in Georgia which illustrates one mode of origin very clearly, while Bastin[3] has described a graphite mine at Ticonderoga, N. Y., which illustrates a wholly different mode of origin.

The peculiarity of the Montana graphite property is that it seems to illustrate different modes of origin in a single deposit. Thus, the seams of graphite strictly parallel with the bedding in marbleized limestone and in quartz schist may well represent the result of metamorphism of carbonaceous layers in those rocks. It is doubtless true that the metamorphism of such carbonaceous layers usually results in producing the so called "amorphous" graphite, which is very fine-grained and usually impure. But it seems probable that more intense metamorphism would produce

[1] Smith, George Otis, "Graphite in Maine," Bull. U. S. Geol. Survey, No. 285, 1906, p. 480.

[2] Bull. U. S. Geol. Survey, No. 340, 1908, p. 463.

[3] "Mineral Resources U. S. for 1908," U. S. Geol. Survey, 1909, pp. 729–731.

coarser and purer graphite such as that actually occurring in the Dillon deposit.

If metamorphism has converted the carbonaceous matter of shales into graphite *in situ,* it is very probable that it has also in this deposit caused considerable movement of the graphite in some cases. For it is clear that the graphite surrounding garnet crystals in quartz schists nearly devoid of graphite must have moved to its present position, probably through a process of concentration which brought sparsely disseminated carbonaceous matter into concentrated layers of graphite around garnet crystals. If this explanation is correct, the movement, or at least the deposition, of the graphite must have occurred near the end of the period of metamorphism, since it is not enclosed by garnet, but is in and outside of the outer portion of the quartz which encloses the garnet crystals.

If the carbonaceous matter of shales can be moved by metamorphism as just described, there seems to be no reason why carbon in some form should not get into veins, and the solutions which deposit veins. It may be that the graphite in veins near Dillon has originated in this way. One may even go further, and suggest that the graphite in pegmatite and other igneous rocks may have originated in a similar way, that is, by the entrance of carbon in some form into the solutions which form such igneous rocks.

The graphite of igneous rocks and veins is just as truly a primary constituent of the rocks or veins as quartz or feldspar or mica. It is well known that the constituents of igneous rocks have crystallized at high temperatures from silicate solutions. But graphite is practically insoluble in silicates at the ordinary temperatures of magmas; it is upon this fact that its value as a refractory material partly depends. How, then, can the occurrence of graphite as a constituent of igneous rocks and veins be explained?

Numerous suggestions have been made to explain the occurrence of graphite in igneous rocks and veins, but it seems possible to show that many of them are probably incorrect. The intimate

intergrowth of the graphite with quartz and feldspar is evidence that it is not a later introduction into the rock.[1] That the graphite did not exist in the silicate solution in the form of crystal flakes is indicated by the evidence that some of the constituents of the rock are enclosed by the graphite, and also by the fact that the graphite is often very uniformly distributed through the rock. That the graphite did not exist in the silicate solution in the form of liquid or gaseous carbon in solution is indicated by the refractory character of the mineral, which is practically insoluble in molten magmas at the temperatures ordinarily attained by such magmas. The temperatures of liquefaction and of vaporization of graphite are known to be about 3000° C.; the present condition of the minerals and rocks associated with the graphite shows that they were not subjected to any such temperatures at the time when they, together with the graphite, assumed their present condition. Therefore the suggestion[1] sometimes made that sublimation from carbon vapors is responsible for the formation of graphite in veins seems highly improbable.

The evidence seems convincing that the graphite of igneous rocks and of veins, immediately before deposition in its present form, was a constituent, in some form, of the solutions from which the rocks and vein materials crystallized. It also seems clear that the graphite could not have been in those solutions either in the form of solid undissolved carbon, or in the form of solid carbon in solution, or in the form of liquid or gaseous carbon, dissolved or undissolved. Therefore, the graphite, before deposition, must have existed in the solutions in the form of some compound of carbon.

It has been suggested that the graphite of veins and pegmatites has been derived from volatile hydrocarbons.[2] The suggestion seems plausible, since hydrocarbons, especially methane, are found in volcanic gases[3] and as gaseous constituents of

[1] E. S. Bastin, "Mineral Resources U. S. for 1908," II., pp. 718, 731, U. S. Geol. Survey, 1909.

[2] See, for example, Jacquelain, *Cosmos*, June 23, 1864; T. S. Hunt, "Geology of Canada," 1866, p. 222; F. Cirkel, "Graphite," p. 89, Mines Branch, Ottawa, 1907.

[3] F. C. Lincoln, ECONOMIC GEOLOGY, II., 1907, p. 258.

igneous rocks.[1] Furthermore, when carbon and aqueous gas interact at temperatures above about 600° C. hydrogen is produced. A part of the hydrogen thus produced may combine simultaneously or later to produce various hydrocarbons, especially methane, CH_4. If other hydrocarbons form, heat alone will decompose them[2] with the production of methane, hydrogen and minor amounts of carbon and tarry compounds. This decomposition is progressive and practically complete at 800° C. At that temperature methane begins to decompose, and its destruction to form carbon and hydrogen is nearly complete at 1100° C. But methane in the presence of aqueous gas[3] reacts to form CO and hydrogen at much lower temperatures. In fact the reaction is complete at red heat, 500°–700° C. It is clearly reversible, as the Elworthy[4] process for the manufacture of methane demonstrates. The reaction is: $CH_4 + H_2O \rightleftarrows CO + 3H_2$. But whether these hydrocarbons form or not, it seems improbable that they are the source of graphite deposits, for several reasons. First, in the presence of water they will apparently be wholly transformed into carbon monoxide and hydrogen at 700° or 800° C. Second, in the absence of water the decomposition of hydrocarbons occurs at high temperatures[5] (acetylene 650°–800° C.; ethylene 500°–800° C.; ethane 600°–800° C.; methane 800°–1150° C.) and with rising temperatures; any graphite that resulted from such a process should be formed in the hottest part of the intrusive magma rather than in the much cooler solutions which form pegmatites and veins in which the graphite is actually found; third, on cooling below 500°–700° C. hydrogen and the oxides of carbon may react to form methane and perhaps other hydrocarbons, but such reactions are not known to produce graphite. These reactions may be illustrated by: $CO + 3H_2 = CH_4 + H_2O$ and $CO_2 + 4H_2O = CH_4 + 2H_2O$. Fourth, no reaction is known to the writer for the de-

[1] R. T. Chamberlin, "Gases in Rocks," 1908, Carnegie Inst., Publ. No. 106.
[2] W. A. Bone, *Gas World*, June 27, 1908, p. 869.
[3] J. Coquillion, *C. R.*, LXXXVI., 1878, p. 1197. Cited by Hempel, "Gas Analysis," 1906, p. 302.
[4] A. Girard, *Gas World*, December 30, 1905, p. 1226.
[5] W. A. Bone, *Gas World*, June 27, 1908, p. 869.

composition of hydrocarbons (with formation of graphite) below 500° that should be expected under the conditions of formation of pegmatites and veins.

It has been suggested also that the carbon of graphite of igneous rocks and veins existed in the silicate solutions in the form of a carbide of one of the metals, for example, iron. Such a condition seems improbable for several reasons. First, the carbides are not to be expected at high temperatures in the presence of oxygen—(even the relatively stable carbide of iron oxidizing readily at temperatures[1] as low as 150° C.), and oxygen is present in magmas and vein solutions in such abundance that unoxidized elements are almost unknown; furthermore, oxygen is one of the constituents[2] of volcanic gases emanating from magmas. Second, all the metallic carbides[3] (except those of iron, chromium, molybdenum and tungsten) are unstable at high temperature in the presence of water, which is practically always present in abundance in magmas, and still more abundant in vein solutions. In the particular case under discussion, iron carbide as a source of the graphite seems to be ruled out by the fact that almost no iron in any form (and in some cases very little metal of any kind) exists in the rocks containing the graphite. Third, if carbides once existed in magmas, they are to be expected, at least in small amounts, in the rocks derived from the magmas; as a matter of fact, they are unknown in such rocks.

All of these conditions, which are the basis of arguments against the existence of carbides in the magmas and vein solutions under consideration, are at the same time cogent reasons for believing that the carbon existed in them in the form of oxides, possibly associated with hydrocarbons. The existence of oxides of carbon in solution in magmas and vein-forming solutions seems to be clearly indicated by the following facts. First, carbon in any form uncombined and in very many compounds (except when already combined with oxygen) will unite with

[1] H. Moissan, "Traité de Chimie Minérale," IV., p. 392, Paris, 1905.
[2] F. C. Lincoln, Economic Geology, II., 1907, p. 258.
[3] H. Moissan, *loc. cit.*

oxygen very rapidly to form CO, or CO_2, or both. The combination occurs with liberation of a large amount of heat (see Fig. 27) at temperatures varying from 200° to 800° C., when the carbon is previously uncombined. Second, carbon combines with water (aqueous gas) at temperatures above 500°–650° C.

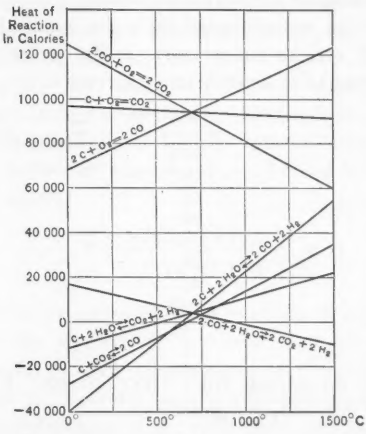


FIG. 27. Diagram showing the heat of reaction in calories at various temperatures for reactions between carbon, oxygen, and hydrogen and oxides of carbon and hydrogen. After Weigert: Abegg's Handb. Anorg. Chem. III, 2, 1909, p. 196. When the heat of reaction is positive the substances named last in the equations are the products of the reaction; when the heat of reaction is negative the substances named first in the equations are the products.

(see Fig. 27) to form H_2 and CO or CO_2 or both, according to the reactions:

$$C + 2H_2O = CO_2 + 2H_2.$$
$$2C + 2H_2O = 2CO + 2H_2.$$

A part of the hydrogen thus produced may combine with carbon to produce various hydrocarbons, especially CH_4. Hydrocarbons as possible sources of graphite have been discussed in preceding paragraphs. Third, oxides of carbon certainly exist in magmas, at least to some extent, since both CO and CO_2 are

important constituents of volcanic emanations,[1] and are also known both mechanically enclosed and also "adsorbed" or dissolved in igneous rocks.[2]

If it be admitted that the oxides of carbon exist in magmas and in vein-forming solutions, it still remains to show that these oxides may decompose and produce graphite.

Boudouard[3] has experimented with the equilibrium between CO and CO_2 at various temperatures in the presence of carbon, and the following table summarizes his results:

Temp. in °C.	$2CO$ Per cent. CO.	$\rightleftarrows$	$CO_2 + C$ Per cent. CO_2.
1000	99.3		0.7
900	96.5		3.5
800	93.		7.
750	76.		24.
700	58.		42.
650	39.		61.
600	23.		77.
550	10.7		89.3
500	5.		95.
450	2.		98.

That is, CO on cooling from 1000° to 500° C. breaks up almost entirely into CO_2 and graphite.[4]

[1] F. C. Lincoln, ECONOMIC GEOLOGY, II., p. 258, 1907; T. C. Chamberlin and R. D. Salisbury, "Geology," I., 1905, p. 618, 619.

[2] R. T. Chamberlin, "Gases in Rocks," 1908, Carnegie Inst., Publ. No. 106.

[3] O. Boudouard, *Ann. Chim. Phys.*, XXIV., 1901, p. 5.

[4] It is true that at atmospheric pressure the experiment of Boudouard yields finely divided carbon ("lamp black"), rather than graphite. But it is known from experiment that such carbon may be converted into graphite by the application of pressure and heat. It is therefore probable that under pressure the experiment would yield graphite directly. Furthermore, crystallization of carbon may occur more readily from liquid solution than from the gaseous state. The crystallization of graphite from carbon in solution under moderate pressure is illustrated by its formation in cast iron. Thus, there is very good reason to believe that this reaction and similar ones, which yield carbon when carried out under atmospheric pressure and in the absence of a liquid solvent, would yield graphite when occurring under pressure in the presence of a liquid solvent. With this explanation, the experiments which yield carbon in gas reactions at atmospheric pressure will be discussed as if they yielded graphite, since it is certain that they yield a product that could be converted into graphite by pressure and heat, and it is probable that under the pressure and temperature conditions of formation of veins and pegmatites they would yield graphite directly.

Weigert[1] discusses the matter theoretically, and concludes that the two reactions by which carbon unites with water to form hydrogen and oxides of carbon are reversible, and that at temperatures below 650°–500° C. the oxides of carbon react with hydrogen to form water and graphite. Hydrogen is known to be present in magmas, sometimes in notable amount.

Weigert's conclusions are shown graphically in Fig. 27. The reversible nature of the reactions $C + CO_2 \rightleftarrows 2CO$ and $CO + H_2O \rightleftarrows CO_2 + H_2$ has been demonstrated experimentally by Boudouard and Dixon[2] respectively. On the basis of these facts and the known heats of reaction at various temperatures it is clear that the following reactions must likewise be reversible, as shown in the figure:

$$C + 2H_2O \rightleftarrows CO_2 + 2H_2.$$
$$2C + H_2O \rightleftarrows 2CO + 2H_2.$$

The reversible character of these reactions is indicated, in the figure, both by the sign $\rightleftarrows$ and by the fact that the heats of reaction are positive at some temperatures and negative at others. When the heat of reaction is positive the tendency in each case is to produce the substances of the right-hand side of the equation, that is, H_2, CO, and CO_2. When the heat of reaction is negative the tendency in each case is to produce the substances of the left-hand side of the equation, that is H_2O, CO, CO_2 and C (graphite).

The equation $2CO + 2H_2O \rightleftarrows 2CO_2 + 2H_2$, tends to destroy CO_2 and produce CO at temperatures above 900° C. At the same temperatures the action of water on carbon should produce chiefly CO rather than CO_2, since the heat of reaction for the former is greater than for the latter. Below 900° C. the reaction $2CO + 2H_2O \rightleftarrows 2CO_2 + 2H_2$ tends to produce CO_2 and hydrogen. Below 500° C. the CO_2 and hydrogen thus produced tend to react to produce water and C (graphite). When water and carbon interact freely the end products of all the resulting reactions at

[1] Abegg's "Handb. anorg. Chem.," III., 2, 1909, p. 196.
[2] H. Dixon, *Jour. Chem. Soc.*, XLIX., 1886, p. 94.

temperatures above 700° C. are CO, CO_2 and H, while above 900° C. the end products are chiefly CO and H_2. Under the same conditions the end products below 500° C. are water and graphite.

All the conditions necessary for the formation of graphite are present in the cooling of an ordinary magma. In ordinary cases the amount of the gases CO_2, CO and H_2, present in magmas is too small to produce any appreciable quantities of graphite; and in so far as they escape into the atmosphere without mutual reaction no deposits of graphite can form. But if any magma should contain abnormally large amounts of these gases, and should solidify at depth so that the gases could not escape, graphite deposits are to be expected.

Furthermore, any magma which contains sufficient water, upon coming in contact with bituminous or carbonaceous shales or slates, may be expected to convert all that portion of the carbon which is heated above about 600° C. to the oxide state through the agency of water. The resulting gaseous hydrogen and oxides of carbon, being soluble in water and silicate solutions under pressure may be expected to move about with, and as freely as, the magmatic solutions themselves. Finally, when these solutions cool below about 600° C., graphite may be expected to crystallize out in much the same way as other minerals crystallize from the cooling magma.

If this explanation of the origin of the graphite of igneous rocks and veins is correct, graphite may serve as another "geologic thermometer" to indicate the temperature of formation of the rocks which contain it. Unfortunately, the reading of this thermometer is somewhat vague, since, according to the table given above, formation of graphite may occur at all temperatures between 1000° C. and 450° C., and even at somewhat lower temperatures; however, more than half of the graphite forms between 750° and 600° C. But the table represents equilibrium conditions at a pressure of one atmosphere. Greater pressures would modify the equilibrium, probably raising the temperature[1] at which a given amount of CO_2 and graphite would be produced.

[1] O. Boudouard, *Ann. Chim. Phys.*, XXIV., 1901, p. 34.

Furthermore, equilibrium may not be reached in all cases. That is, there may be a lag in the reaction. This would result in lowering the temperature at which the graphite crystallized. Recognizing fully these limitations to the accuracy of reading of this thermometer, it still remains true that it corroborates at least in a general way the data obtained by Wright[1] from the study of quartz as a geologic thermometer, if the mode of origin here described is the correct one.

Summarizing as to the origin of graphite, it appears that

1. Graphite is probably formed in nature in several different ways. Graphite in sedimentary rocks may have an origin wholly different from graphite of veins and pegmatites.

2. Confining attention to pegmatites and veins, it is argued that the most probable mode of formation of graphite is by the deoxidation of oxides of carbon.

3. The deoxidation of carbon dioxide may be caused by hydrogen, or other reducing agent.

4. The partial deoxidation of carbon monoxide occurs in the absence of any reducing agent at temperatures below 900° C., according to the reaction:

$$2CO = C + CO_2.$$

5. The oxidation of the carbon of bituminous shales by water (aqueous gas) at high temperatures, its mobility as a consequence of the formation and solution of the oxides, and its reprecipitation in places where the solutions reached lower temperatures may all be explained by appealing to the reversible reactions:

$$C + 2H_2O \rightleftarrows CO_2 + 2H_2.$$
$$C + H_2O \rightleftarrows CO + H_2.$$

ECONOMIC CONSIDERATIONS.

At the present time development has not proceeded far enough to prove the existence of large deposits of graphite on the prop-

[1] F. E. Wright and E. S. Larsen, "Quartz as a Geologic Thermometer," *Am. Jour. Sc.*, XXVII., 1909, p. 421.

erty of the Crystal Graphite Company near Dillon, Mont. But the prospecting done proves the existence of considerable graphite occurring in several different ways, and always of very high grade. A better understanding of the probable mode of origin of the graphite should be of much value in guiding further exploration, both at this locality and elsewhere. It is particularly desirable to recognize in many cases the probable importance of water (aqueous gas) in carrying the heat which metamorphoses carbonaceous shales, and also in oxidizing the carbon and thus rendering it soluble and mobile. At the deposits near Dillon the importance of pegmatite dikes, as the probable source of at least a part of the water concerned, should also be recognized. In some cases these dikes may serve as guides in exploration work. In other cases veins and shear zones must be followed to find the graphite. When it occurs in seams in bedded deposits, there should be no difficulty in following it. But in this case it is important to keep in the region in which the activity of the water was sufficient to produce the change without being sufficient to carry the graphite away.

GEOLOGY OF THE PHILLIPS PYRITES MINE NEAR PEEKSKILL, NEW YORK.

MICHAEL HEILPRIN LOVEMAN.

INTRODUCTION.

TOPOGRAPHY.

The topography of the region surrounding the Phillips Mine partakes of the same characteristics as the Highlands in general. The Hudson River is the dominating feature. Two prominent summits, Dunderberg and Anthony's Nose, and the east slope of a third, Bear Mountain, are included in the area studied. Iona Island, an irregular mass of crystalline rocks, juts up out of the Hudson just north of the projecting buttress of Dunderberg. The country is extremely rugged and well wooded and as a consequence is very sparsely inhabited.

GEOLOGY.

The entire district has suffered intense metamorphism, due both to folding and to the great number of igneous intrusions. The folding was undoubtedly accompanied by faulting, probably on a large scale, but the lack of well-defined horizons by which to make a comparison between the opposite walls has concealed it. Sheared or crushed zones are often exposed and probably represent faults. It seems probable that Dunderberg and Anthony's Nose represent the core of an eroded anticline and that the sediments on both sides are in the troughs of synclines.

All the rocks of the section are crystallines and include typical coarse grained granites, syenites, diorites and dark basic dikes, on the one hand, and finely foliated quartzose graphite schists, mica schists and impure crystalline limestones on the other. Intermediate between these two classes of rocks, and covering a large proportion of the district, are the fine and coarsely foliated

gneisses, generally showing a rapid alternation of bands of light and dark varieties. The light types are composed essentially of feldspars and quartz, generally with the feldspars in excess; the darker types have as their predominant component a ferromagnesian mineral, generally hornblende, although its place is frequently taken by biotite or augite.

For the purposes of description and mapping the rocks of the district have been divided into three classes: gneisses, igneous rocks and undoubted sediments.

The Gneisses.—The gneisses are the oldest and among the most abundant rocks of the district and tend to form the more conspicuous summits. They afford a great variety of rock types, including granitic, amphibolitic, pyroxenic, micaceous, and quartzose gneisses. In some cases the banding is a rapid alternation of thin seams of dark and light minerals, most often amphibole and feldspar, or amphibole and quartz. From this type, in which the bands are only a fraction of an inch in thickness, gradations can be traced up to broad bands of several feet in width of the same variety of minerals. In great part, these may be sedimentary in origin, but as the Highlands have been subjected to a long series of disturbances, and as the banded gneisses are the oldest rocks present, one has no difficulty in accounting for metamorphism severe enough to have completely obliterated their original characters.

The Igneous Rocks.—A perfect gradation of igneous types from granites through syenites and quartz diorites to rather basic pyroxene diorites is present within this area. If the dikes are included in this class the extremes are even further apart, ranging from pegmatites to dark basic dikes. The granites are far more abundant than any of the other varieties. In textures also, all gradations from extremely coarse pegmatites to very fine grained granites are present. All the igneous rocks of the district are, however, distinctly holo-crystalline, no porphyritic, felsitic or glassy textures have been observed. The igneous rocks are very abundant and, together with the banded gneisses, compose at least nine tenths of the district. They are all younger than the banded

gneisses and vary greatly in age among themselves. With the exception of the dikes, there is absolutely no regularity in the shape of the igneous intrusions.

The Sediments.—On the map a uniform symbol has been used for all the sediments irrespective of the marked differences which exist between them. This was necessary because of the fact that they are present in such small quantities and in such intimate relations to each other. The sediments may be divided into four classes, the quartzites, the limestones, the shales or mica schists, and the graphitic schists.

The quartzites are the most difficult of all the metamorphosed sediments to recognize, principally because slight impurities in the original sandstone cause the rock on metamorphism to assume an aspect closely resembling that of an igneous rock.

The limestone, although the least extensive of any formation in the district, is perhaps the most important both because of its pronouncedly sedimentary character and because of the great value which it has as an horizon of reference. It is often extremely graphitic, the flakes of graphite being oriented in a definite direction.

The mica schists were undoubtedly originally argillaceous sediments probably closely approaching shales. Those found here closely resemble the Manhattan schist of New York city, although not so intensely crumpled. The light-colored minerals are largely concealed by the biotite which gives the rock a dark, almost black, appearance.

The graphitic schists are the most extensive of any of the sedimentary formations and are, in addition, very easily recognized. They are variable in their composition, and include feldspathic, micaceous and quartzose phases. The graphite occurs in flakes varying from very minute specks up to particles a quarter of an inch or more in length, usually oriented with their longer axes parallel to the foliation or strike of the containing rock. The percentage of graphite varies from only a trace up to a preponderance over all the other minerals combined. The latter condition is, however, unusual.

GEOLOGICAL HISTORY.

In a general way the following sequence of events represent the past history of the region. In remote pre-Cambrian time, on a surface which is at present nowhere visible, a series of sediments were laid down consisting probably of sandstones and shales and, more doubtfully, of limestones. After the deposition of the sediments extensive folding and metamorphism took place. Either contemporaneously with this folding or later, the sediments were cut by dikes and sills of igneous rocks. Following these events, and at a much later time, a second series of sediments were laid down. After the deposition of these beds, folding and metamorphism again took place. The sandstones were changed to quartzites often so graphitic as to be properly called graphite schists, the shales to mica schists, the limestones to impure marbles. The second series of sediments is easily distinguished from the first both by the fact that the metamorphism has been far less severe, leaving the original clastic origin still plainly evident, and by the additional fact that the intrusions of igneous matter which so greatly altered and changed the character of the first series of sediments and which were bodily incorporated into it, are lacking. This second series was undoubtedly originally unconformable with respect to the underlying rocks, but subsequent metamorphism has entirely obliterated this relationship and induced an apparent conformity between the two. Following this second period of folding came the most pronounced igneous activity. Great masses of granite, syenite, diorite, and other holo-crystalline types were intruded into the overlying rocks. Some of these intrusions were probably contemporaneous with the last period of folding, possibly representing one of the factors which caused it. The various intrusions took place, however, at widely different epochs. The last stage in the igneous history of the region is marked by the intrusion of pegmatites and various basic dikes. The pegmatites cut all the other rocks of the district and are probably the youngest consolidated rocks present. The post-Cambrian history of the region has been largely obliterated by erosion.

THE PHILLIPS PYRITE MINE.

The Phillips Mine is situated on the northeast spur of Anthony's Nose, about 700 feet above the Hudson, and at a distance of about one and one-half miles from the Manitou Station (Highland Station) of the N. Y. C. & H. R. R. R. The mine is opened by a shaft and two tunnels. The upper tunnel has its portal about fifty feet below and ninety feet to the west of the outcrop of the ore, and the lower tunnel, about 100 feet below and 300 feet to the west. The ore body dips to the northwest at a high angle, about 70 degrees, and strikes northeast in conformity with the general strike of the surrounding formations. The direction of the dip is rather unusual for the deposits of the Highlands, the large majority being towards the southeast. It is not, however, the only exception. The deposit has been mined for several hundred feet on the strike and somewhat over a hundred feet down on the dip. Its thickness, about 15 to 25 feet, is fairly constant but the manner in which it thins out and finally disappears towards the southwest (the northeast end has not been uncovered) seems to indicate a lens-like form. The ore consists largely of pyrrhotite, slightly nickeliferous, with smaller amounts of pyrite, magnetite and chalcopyrite. The gangue is chiefly hornblende and feldspar with smaller amounts of other minerals. Well formed crystals of apatite are common.

The original owners had hopes that it might become richer in copper in depth after the manner of the deposits at Ducktown, Tenn., and also entertained hopes of extracting payable amounts of nickel, but neither of these expectations were realized. An analysis of the ore given by Professor J. F. Kemp in the *Trans. Amer. Inst. Min. Eng.*, vol. 24, shows Sulphur, 30 per cent.; Copper, .5 per cent., and Nickel, .3 per cent.

The sulphur was the only product from which any returns were realized. Owing to the fact that no trace of arsenic was present in the ore a C.P. acid could be made from the fumes. Acid works were constructed on the shore of the Hudson and were for some time supplied with ore from the mine. The mine, has, however, been idle for many years.

The rocks in the district surrounding the mine are granitoid, gneissoid and schistose, with a wide range of mineral composition and with origins which were in some cases undoubtedly igneous, in others sedimentary, and in still others indeterminable. Although some of the rocks in the vicinity of the mine are undoubtedly of sedimentary origin as, for example, a graphitic schist about a quarter of a mile to the north, yet a microscopic determination has shown that the ore body itself is entirely enclosed in igneous rocks. Although microscopic examination shows important differences among these rocks, the following generalizations hold true for all of them: The rocks have a typical granitoid texture. Reabsorption, to a greater or less extent, is present in all the slides. The plagioclases, generally of the albite and oligoclase varieties, are large and abundant and show a marked development of polysynthetic twinning. Large crystals of green pyroxene are present in several of the slides and, when absent, their place is taken by amphibole (uralite) which was probably derived from them. The accessory mineral, ilmenite, and in some cases zircon, generally characteristic of igneous rocks, are practically always present.

The above facts show quite conclusively the igneous character of the country rock on all sides of the ore body. This proves that the ore body cannot belong to the class of metamorphosed sedimentary deposits. Hence there remain only two rational suppositions, either that the deposit has been formed by deposition from mineral-bearing solutions, or, that it is the result of segregation from a molten magma. Before taking up the discussion as to which of these two methods of origin is probably nearest the truth, it will be necessary to describe in more detail the surrounding rocks and the ore itself.

The wall rock directly adjacent to the ore on both the hanging and foot walls is a medium gray granitoid, rock. It consists largely of plagioclase and pyroxene with varying amounts of quartz, orthoclase and various secondary and accessory minerals. The plagioclase, the most abundant mineral present, is intermediate between albite and oligoclase. It occurs in large grains

with the polysynthetic twinning strongly developed. Light green pyroxene with well marked cleavage is, after the plagioclase, the most important constituent of the rock. Alteration of the pyroxene to amphibole is quite common: in fact, in the specimens from the foot wall the secondary amphibole is almost equal in amount to the pyroxene. Quartz is present in variable amounts, in some slides almost dropping out altogether, while in others it is present in such quantities as to become one of the principal minerals. The conditions in which it is found are also quite variable, in some cases filling in the spaces between grains of other minerals, according to the normal behavior of quartz, while in other instances it is found entirely included within plagioclase or even within pyroxene. It is entirely devoid of crystal form and when occurring as inclusions in other minerals is generally almost circular in outline. It is freer from inclusions than the surrounding minerals. The anomalous position of the quartz seems to point towards a secondary origin for it, a probable later introduction into shattered rock and the filling in of interstitial cavities in the grains of the older minerals. Microcline occurs as narrow borders often around the quartz. Biotite, probably always secondary, is present in small amounts. Apatite, which is rather abundant, appears to be universally biaxial. This anomalous behavior of the apatite was noticed by Koeberlin in the syenite country rock surrounding the Croton iron ore body.[1] All the ore minerals of the deposit itself are found disseminated through the enclosing rock. Pyrite, pyrrhotite, magnetite and possibly chalcopyrite are all present in considerable amounts. Pronounced reaction rims have formed around the grains of magnetite; successive fringes of titanite and biotite often encircle it. The presence of the titanite as a secondary product from the magnetite and the additional fact that the magnetite in many cases has altered to leucoxene shows that it is highly titaniferous, very probably ilmenite. As far as it was possible to determine, the relative ages of the sulphides and the titaniferous magnetite are as follows. Pyrite is the oldest mineral, magnetite is inter-

[1] F. R. Koeberlin, "The Brewster Iron-bearing District of New York," ECON. GEOL., IV., 744, 1909.

mediate in age, pyrrhotite and chalcopyrite are the youngest. The actual age relations of the last two in respect to each other could not be determined. The severe strains to which the rock has been subjected are clearly shown by the bent and wedging twins of the plagioclase grains. The rock is a pyroxene diorite (Fig. 28).

The rock at the mouth of the upper tunnel, about 30 yards west of the ore body, is radically different in appearance from

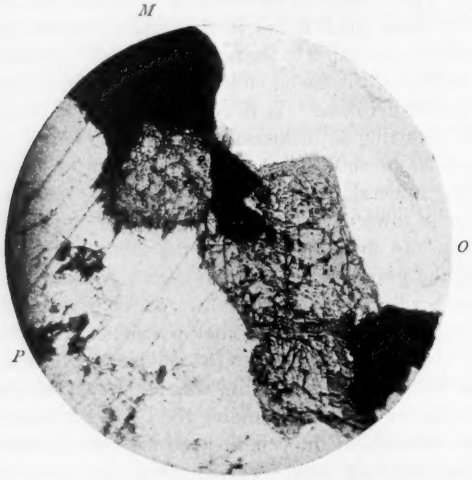


FIG. 28. Microphotograph of wall rock of mine. M = magnetite, O = orthoclase, P = plagioclase.

that immediately enclosing the ore. While the latter is a massive granitoid rock, this is strongly gneissoid with well-defined bands of feldspar and hornblende. A microscopic examination shows that it is composed essentially of feldspar and homblende. The feldspar is present both as plagioclase and orthoclase in about equal amounts. The presence of orthoclase in such large amounts is in rather marked contrast to the relative scarcity of that mineral in the wall rock of the mine. The feldspars are

extremely mottled in appearance, giving them in many cases a grayish color. This mottled appearance is due to an abundance of inclusions and not to kaolinization or any other alteration. Quartz practically fails. Amphibole is present in amounts approximately equal to the feldspars. Whether it is present as an original mineral or as an alteration of pyroxene could not be positively determined, although the latter view appears to be the correct one, as the amphibole has all the characteristics of uralite

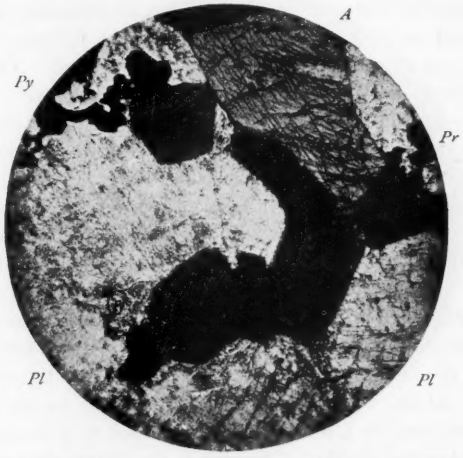


FIG. 29. Microphotograph of monzonite intrusion northwest of mine. *Pr* = pyrrhotite, *Py* = pyrite, *Pl* = plagioclase, *A* = amphibole.

and in a few instances traces of original pyroxene were observed. The ores, pyrite, pyrrhotite, and titaniferous magnetite are very abundant, occurring disseminated all through the rock. The rock is undoubtedly igneous in origin and has probably had its gneissoid form imposed upon it since its original consolidation. It is probable that much rearrangement took place during metamorphism and that the origin of the amphibole dates back to that period. Wavy extinction of some of the feldspars and the bent

twins of the plagioclase are witnesses to the dynamic strains to which the rock has been subjected. The amounts of plagioclase and orthoclase are so nearly equal that the rock can best be described as a basic monzonite metamorphosed to a monzonite gneiss (Fig. 29).

The rock at the mouth of the lower tunnel closely resembles that from the upper. Alteration of the original minerals and consequent formation of secondary products has, however, taken place to a greater degree. In one slide examined, practically the entire rock had been affected, and the only remaining signs of the original minerals were the outlines of the feldspar crystals, the bodies of the crystals being entirely obliterated. The result of the alteration has been the formation of a scaly colorless product, composed of an aggregate of secondary minerals, largely zoisite, with smaller amounts of serpentine, chlorite and kaolin. A few shreds of mica, doubtless also secondary, are visible. The zoisite has been formed by the alteration of the lime-bearing plagioclases. Amphibole is the predominant constituent followed by plagioclase and orthoclase. Quartz is present in small amounts. The feldspars have in many instances eaten into the amphiboles, due either to a later crystallization or to a reabsorption process in the course of the subsequent metamorphism. The rock is closely similar to those described from the mouth of the upper tunnel, with the exception of the fact, as has already been stated, that the alteration has progressed to a much greater degree. Another point of difference is the virtual disappearance of the disseminated sulphides and magnetite.

The rocks just described are either directly adjacent to the ore body or else they occur parallel to the deposit along the north west side and not more than a few hundred feet from it. Farther from the ore body, and both to the north and south of it, is a fine grained granite or quartz diorite. This rock covers a much wider area than either of the others and appears to be the real country rock of the neighborhood, the more basic ones just described being intrusions into it. In this rock amphibole and biotite in extremely small amounts are the only representatives of

the ferro-magnesian minerals. The principal minerals are the feldspars and quartz. Quartz is very abundant, about equal in amount to all the feldspars combined. Replacement of the feldspars by the quartz is quite common. The former are about equally divided between plagioclase and orthoclase. They are extremely mottled in appearance apparently due to inclusions. The quartz grains, on the other hand, are quite clear. Micro-

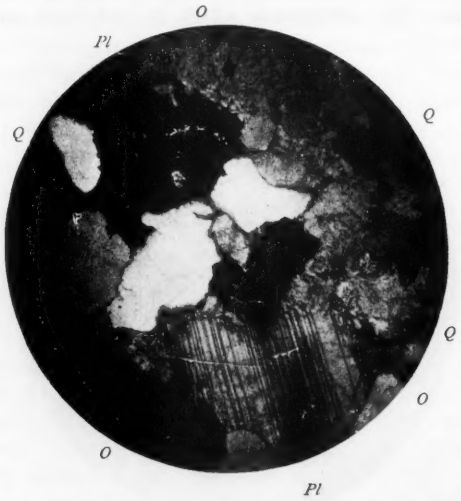


FIG. 30. Microphotograph of granite or quartz diorite, the real country rock of the district surrounding the mine. *Pl* = plagioclase, *O* = orthoclase, *Q* = quartz.

cline is frequently developed as fringes around other minerals. This rock has been designated as a granite or quartz diorite but it must be admitted that its igneous origin cannot be positively proved. It is gneissoid in appearance, microgranular in texture and contains no minerals which could not have been formed in the metamorphism of an impure sandstone. On the other hand, the general relation of the minerals to each other, and the large

proportion of feldspars seem to point to an igneous origin (Fig. 31).

An examination of a thin section of the ore itself showed that, except for a great increase in the proportion of the sulphides in respect to the rest of the minerals, it is essentially the same as the wall rock of the mine.

Plagioclase and amphibole, the latter probably derived from pyroxene, are the essential minerals just as in the hanging and foot walls. The relations in which the sulphides, pyrite and

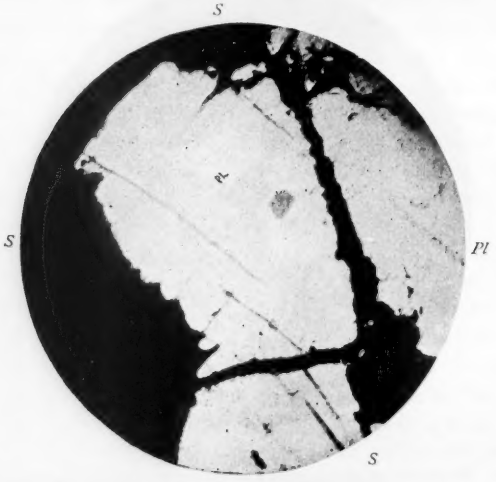


FIG. 31. Microphotograph of ore, showing the later introduction of the sulphides. S = sulphides, Pl = plagioclase.

pyrrhotite, are found are such that their later introduction cannot be doubted. Grains of plagioclase and amphibole are often completely surrounded by irregular zones of sulphides which, in addition, often penetrate into the silicates along cracks and shattered strips. In many cases the sulphides appear to have replaced portions of the grains of feldspars and amphiboles. The pyrite is older than the pyrrhotite and was broken up and shat-

tered before the introduction of the latter. The pyrrhotite fills in the spaces between the broken grains of pyrite and often completely encloses them.

The intrusion of pyroxene diorite strikes northeast with the same general trend as the surrounding formations. It is much longer than wide, being simply a dike of large dimensions. It is apparently slightly mineralized at a number of places along the strike since numerous prospecting pits have been sunk but with negative results. A microscopic examination of a specimen from one of these pits about 300 yards southwest of the Phillips Mine, showed that it is almost identical with the wall rock of the mine. The only points of difference are that the sulphides are absent and that the included grains of quartz are less numerous.

SUMMARY.

In the slides that have just been described it is evident that three distinct types of rock are present. The first, a pyroxene diorite, which forms the walls of the ore body, is a massive granitoid rock consisting originally of plagioclase and pyroxene, but now changed by the introduction of quartz and the alteration of the pyroxene to amphibole. The second type forms a rather narrow band bordering on the first to the northwest and running parallel with it. The actual contact between the two could not be observed. This rock is extremely gneissoid with rather coarse alternating bands of amphibole and feldspar. It was originally closely akin to a monzonite. That these two rocks are distinct masses and not simply the differentiation of a single mass into two phases, seems certain. The third type, much the most widely extended of the three and apparently the real country rock of the district surrounding the mine, is a fine grained granitoid rock, somewhat gneissoid in appearance and consisting of quartz and feldspar and minor amounts of hornblende and biotite. The quartz of this rock appears to be in large part original. It is present in large amounts, and forms approximately 50 per cent. of the total.

A sedimentary origin for the ore deposit is evidently im-

possible as it is entirely enclosed in an igneous rock. The relation of the ore to the gangue as evidenced by a microscopic examination, shows conclusively that it cannot have been a product of an original differentiation from an igneous magma. The sulphides are plainly younger than the rock in which they are contained, often either completely enclosing some of the silicates or penetrating into them along cracks, positions which could only be assumed by minerals which have either been the last to form or have entered after the original consolidation of the rock. That the sulphides should be the last to form would be directly opposed to the general rule for precipitation from an igneous solution. In addition, the manner in which they penetrate into the silicates along cracks could only be explained by the shattering of an aleady consolidated mass and the subsequent introduction of the materials which fill up the cracks. Another fact which tends to disprove magmatic segregation is the difference in age between the pyrite and the pyrrhotite. The pyrite is older than the pyrrhotite and was badly shattered and broken up before the introduction of the latter. Thus it is evident that the pyrrhotite, which is the principal ore of the mine, was introduced at some stage later than the original consolidation of the rock which contains it. Still another fact is the position of the ore body in relation to its enclosing rocks. The usual position for basic segregations is along one rim of the parent igneous mass. In this case no such relation can be observed. The deposit is bordered on both sides by a pyroxene diorite.

The following explanation seems best to account for the observed facts. The country rock of the district, which has been designated as a granite or quartz diorite, but which may possibly have been an impure sandstone, had two distinct masses intruded into it. First, the strongly gneissoid rock which as been called a rather basic monzonite appeared. Following this the district was subjected to dynamic disturbances which produced the strongly gneissoid character of the intrusion and which may have produced the same structure in the granitic country rock, or, if the latter was originally a sediment, may have converted it into

its present condition. This last change may, however, have antedated this period and have been simply accentuated by it. At some later date, the pyroxene diorite, the wall rock of the mine, was intruded along the contact between the monzonite and the gneissoid granite. That this second intrusion is separated from the first by a period of disturbance is shown by the strongly gneissoid nature of the monzonite as contrasted with the very massive character of the pyroxene diorite. That these two intrusions were derived from the same source seems quite probable as the most marked differences between them are textural rather than mineralogical. The monzonite along the border near the pyroxene diorite has developed a coarsely pegmatitic phase, consisting largely of hornblende and feldspar, sometimes grading into almost pure massive hornblende. At some indeterminable period in its history this second intrusion was broken by a fault or, more properly, by a crushed zone. Along this crushed zone, waters arose carrying pyrite in solution. The pyrite was deposited in the cavities and interstitial spaces of the shattered rock and in part replaced the silicates of the diorite. Following this period further shattering took place and the pyrite was in turn broken up, making room for the pyrrhotite which was then deposited in the same manner as the pyrite had been before, but in greater amount. The magnetite appears to have formed at some intermediate stage between that of the pyrite and the pyrrhotite. Just at what period the precipitation of the small amounts of chalcopyrite should be placed could not be determined but it was probably simultaneous with the formation of the pyrrhotite. Quartz, probably partly derived from below and partly from the rock itself, was being introduced and rearranged during the whole process of the vein formation. The very intimate manner in which it appears as inclusions in the other minerals has been already pointed out.

The introduction of the sulphides was not entirely confined to the shattered zone. The mineral-bearing solutions invaded the wall rocks and penetrated a short distance into the monzonite to the northwest of the ore body. That this invasion was, however,

limited in extent is shown by the fact that the rock at the mouth of the upper tunnel, about 100 ft. from the ore body, is quite rich in disseminated sulphides while that from the mouth of the lower tunnel, about 300 ft. distant from the ore, is practically free from them.

The fact that the pyroxene diorite from the pit about 300 yds. southeast of the mine is free from sulphides and contains smaller amounts of the included quartz, falls in very well with the genesis outlined above. For, if it is assumed that the deposit was formed by infiltration along a shattered zone, it is only along this zone that the introduced minerals, the sulphides and to a lesser extent the quartz, should be found. It is probable, however, that the pyroxene diorite was a line of weakness and that the shattered zone followed along it, attaining its maximum development at the site of the ore body, but having smaller local development at other spots, which became places of slight mineralization. It was at these slightly shattered spots that the test pits have been sunk along the strike of the diorite but as was evidenced by a microscopic examination, the shattering was not pronounced enough to allow the introduction of appreciable amounts of sulphides.

The ultimate source of the ore cannot be stated with any approach to certainty, but the most reasonable supposition is that it was derived from the same magma as the pyroxene diorite itself, probably as an expiring manifestation.

CERTAIN NATURAL ASSOCIATIONS OF GOLD.

FRANCIS CHURCH LINCOLN.[1]

INTRODUCTION.

The associations of gold in nature are of great interest to both scientist and miner. This contribution presents briefly some of the hitherto recorded facts concerning such associations. It embraces also the results of the writer's own investigations together with certain inferences which the data suggest.

The subject divides itself naturally into two distinct parts:— Associations of Gold with Rocks, and Associations of Gold with Minerals.

PART I: ASSOCIATIONS OF GOLD WITH ROCKS.

I. GENERAL CONSIDERATIONS.

A description of an occurrence of gold in a rock is not satisfactory unless it covers three points: (1) The method by which the presence of the gold was determined, (2) the nature of the gold, and (3) the character of the rock.

The distinction between fragmental and igneous rocks is easily made. Metamorphic rocks are, on the other hand, frequently confused with those which are purely igneous. It is of importance to differentiate between these two groups when discussing an occurrence of gold. The presence of primary gold in a metamorphic rock does not necessarily imply that the rock from which it was derived contained primary gold, for the gold may have come from secondary deposits in the original rock or have been introduced during the process of metamorphism. In the preparation of the table illustrating the occurrence of primary gold in metamorphic rocks which accompanies this paper, several in-

[1] Mining engineer and geologist, 104 John Street, New York City.

stances of the confusion of metamorphic with igneous rocks were noted. The quartz-diorite gneiss, number ten in the table, was first described as an igneous rock; the author himself did not distinguish between igneous diorite and metamorphic hornblende-schist in his descriptions of numbers six, seven and eight; while number thirteen, which from the published figure appears to be a gneiss, was not named by its describer and has since been cited as an igneous rock. Igneous dikes and precipitated veins grade into each other to such an extent that instances near the dividing line may be placed in one group by one author and in the other group by another. A case in point is the Passagem gold deposit in Brazil which Hussak[1] has called a pegmatite and Lindgren[2] a vein.

In the early days of mining geology, the great distance to which impregnation and replacement of rock in the neighborhood of a vein can extend was not realized, and many of the analyses made then indicate rather the extent of such mineralization than primary gold content in the wall rock. Even today, when precautions are taken to secure samples which are apparently fresh and at a distance from known mineralization, it is probable that some, and possible that most, of the gold reported as primary is in reality secondary. The only way in which this can be settled with any degree of certainty is by the examination of thin sections of the rock under a microscope.

The gold content of many rocks lies in the ninth decimal place, which means that it is measurable in units of milligrams per metric ton, or in tenths of a cent per ton. The quantitative determination of such minute amounts of the precious metal naturally requires the exercise of the greatest care, no matter what method may be employed. Don[3] considered that there were four methods which might be applicable: (1) Skey's method[4] of extraction by iodine or bromine, (2) chlorination, (3) fire assay and (4) cyanidation. The first two methods he

[1] *Zeit. für prakt. Geol.*, 6, 1898, 345.
[2] *Trans. Am. Inst. Min. Eng.*, 30, 1901, 626.
[3] *Trans. Am. Inst. Min. Eng.*, 27, 1898, 564.
[4] *Chem. News*, 22, 1870, 245–6.

found unsuitable, but since with the fire assay he was able to detect amounts as low as 0.1 grain per long ton—equivalent to 6.4 milligrams per metric ton—he did not experiment with the fourth method. Subsequently Wagoner[1] successfully employed a cyanide treatment for the determination of similarly minute amounts of gold.

The fire assay is applicable to rocks in much the same way as to ores, save that larger quantities of rock must be taken in order to obtain appreciable amounts of gold. This procedure entails the use of large amounts of fluxes which introduces a serious objection to the method. All the fluxes may contain very small amounts of gold, and in the case of litharge, the content is liable to be both appreciable and irregular. Special precautions are necessary to insure the purity of the litharge.[2]

If the samples could be mechanically concentrated without great loss before assaying, this difficulty would be obviated. Don's experience convinced him that the Australian rocks could be safely concentrated by panning before assaying. Wagoner found that the rocks with which he experimented could not be safely panned since the gold was washed away with the lighter material. Chance[3] has shown that even in the case of a high grade gold ore the major part of the gold may wash away with the tails instead of remaining behind in the concentrates. The siliceous ores of the Ragged Top District in the Black Hills carrying from $100 to $200 in gold per ton fail to yield a concentrate running over $10 per ton. It therefore appears that some of Don's results may have been vitiated through his employment of panning.

Briefly stated, the cyanide method as developed by Wagoner consists in treating pulverized rock with a solution of potassium cyanide in a stoppered bottle, filtering, evaporating the filtrate with calcined lead acetate, and treating the residue on charcoal to obtain a gold and silver button which is parted and the gold

[1] *Trans. Am. Inst. Min. Eng., 31,* 1902, 798.

[2] Andrew emphasizes the difficulty of obtaining pure litharge in *Inst. of Min. and Met. Bull., 64,* 1910.

[3] *Trans. Am. Inst. Min. Eng., 29,* 1900, 228.

estimated by measurement under a microscope. This method has the advantage over fire assaying that it employs fewer reagents and a smaller amount of objectionable lead salt, but this advantage is offset by the fact that the extraction by cyanide is not complete so that the results obtained are always too low. The method, however, appears to be a valuable one, and it is to be regretted that its reliability has not been tested by some other investigator.

When gold is present in exceptionally large amounts, it may be visible in thin sections viewed under the microscope, or even to the naked eye. In such cases its color and luster are usually sufficient identification, but if the slightest doubt as to its identity exists, the mineral should be tested with acids.

II. GOLD IN IGNEOUS ROCKS.

In Table I. there are collected 46 cases of what have been regarded as occurrences of primary gold in igneous rocks, and 2 cases which on careful examination failed to show as much as 6.4 milligrams of gold per metric ton. A forty-ninth case, that of a gold bearing olivine-rock from Otjmbinque, Damaraland,[1] was originally included in this table, but in a private communication to the writer Dr. Scheibe states that the rock is really an epidote-garnet-rock of contact metamorphic origin. No examples have been retained in which it is believed the gold was not determined by a reliable method. The relative reliability of the instances cited has been indicated by attaching a weight to each, the weights employed ranging from 0 to 3. No weight has been attached to 2 cases in which there is a decided doubt as to the true igneous character of the rock. In 24 examples there is no more than a possibility that the gold is primary. These have been given a rating of 1. A weight of 2 has been assigned to 19 observations in which the gold is probably primary. Only 6 citations have been considered worthy of the highest weight, 3.

The discussion of the primary gold content of igneous rocks will be confined to the 25 cases having weights of 2 or 3 and in

[1] R. Scheibe, *Zeit. deut. geol. Ges., 40,* 1888, 611.

which the gold is either probably or positively primary. Quantitative estimates of the gold in these rocks are given in 17 instances. If these figures are examined it at once becomes apparent that some of them are abnormally high. Assayers tell us that while they quite frequently get traces of gold from rocks, they rarely get ponderable amounts. An assayer's "trace" usually means less than 10 cents per ton avoirdupois—equivalent to 166 milligrams per metric ton. 12 of the 17 cases under consideration have less than 166 milligrams of gold per metric ton, the remaining 5 having several times that amount. The average gold content of these 12 rocks—on the assumption that the terms "as much as" or "less than" a specified amount mean an average of one-half that amount—is 62 milligrams per metric ton.

Of the 25 rocks under discussion, 7 are basic, 6 of intermediate composition, and 12 acid. The relative abundance of examples from the three grand divisions of igneous rocks corresponds roughly with the relative abundance of the members of these groups in nature,[1] and tends to prove a rather even distribution of gold irrespective of the chemical composition of the rock. Throwing out the abnormally high cases, just as before, it will be found that of the 12 examples retained 4 are basic with an average of 72 milligrams, 2 intermediate with an average of 3 milligrams, and 6 acid with an average of 76 milligrams of gold per metric ton. It will be observed that the averages for acid and basic rocks are practically identical. The intermediate rocks are both from Australasia and are not known definitely to contain any gold. It is reasonable to suppose that if assays of intermediate igneous rocks from other parts of the globe had been averaged with these, the result would be higher; while if Australasian rocks of acid and basic compositions had been assayed and included in the above computations, the average results for these groups would be lower.

[1] No exact quantitative data are available, but basing the relative quantities of rocks in each of the three groups upon the relative number of analyses from each of these groups as given by Washington, U. S. Geol. Sur. Prof. Paper, *14*, 1903, 102–3, the figures are 45.1 per cent. acid, 32.4 per cent. intermediate and 23.5 per cent. basic.

TABLE I.

PRIMARY GOLD IN IGNEOUS ROCKS.

No.	Division.	Rock. Name.	Locality.	Contents. Gold.	Contents. Silver.	Weighting. Character of Rock.	Weighting. Primary Gold.	Weighting. Wt.	Authority.
1	Basic	Nickel-iron meteorite	Boolgaldi, New South Wales	Trace	———	Igneous	Positive	3	A. Liversidge, *Jour. Roy. Soc. N. S. W.*, *36*, 1902, 349.
2		Sulphide segregation in norite	Sudbury, Ontario	160 + mgs. per m.t.	5,049 + mgs. per m.t.[1]	"	Probable	2	A. P. Coleman, Rep, Bur. Mines Ont., *14*, 1905, 153.
3		Sulphide segregation in norite	Ringerike, Norway	(Present in derived matte)	———	"	"	2	J. H. L. Vogt, *Zeit. prakt. Geol.*, *10*, 1902, 259.
4		Sulphide segregation in uralite-gabbro	Evje, Norway	24 + mgs.	3,333 + mgs.[2]	"	"	2	J. H. L. Vogt, *Zeit. prakt. Geol.*, *10*, 1902, 259.
5		Monchiquite	Krynka River, Russia	739 mgs.	24,740[3]	"	"	2	J. Morozewics, *Mém. Comité Géol.*, N. S., *8*, 1903.
6		Diabase porphyry	Loja Province, Ecuador	Trace	———	"	Possible	1	T. Wolf, Abst. by vom Rath, *Sitzungsber. niederrh. Ges.*, 1879, 192.
7		Diabase	Washoe District, Nevada	As much as 66 to 83 mgs.	7,200[4]	"	"	1	G. F. Becker, U. S. G. S. Mon., *3*, 1882.
8		Diabase	Victoria Placer, Surinam	200 to 600	———	"	"		G. C. Du Bois, *Tscher. min. u. pet. Mitth.*, *22*, 1903, 40.
9		Diabase	British Guiana	Trace to 1,084	———	"	"		J. B. Harrison, "Geology of the Goldfields of British Guiana," 1908, 207.
10		Diabase	Mariposa County, California	76	7,440	"	Probable	2	L. Wagoner, *Trans. Am. Inst. Min. Eng.*, *31*, 1902, 798.
11		Basalt	Petaluma, California	26	547	"	"	2	L. Wagoner, *Trans. Am. Inst. Min. Eng.*, *31*, 1902, 798.
12		Basaltic tuff	Richmond River, New Zealand	15,180	———	May be water deposited	Possible	0	K. Schmeisser, "Die Goldfelder Australasiens, 1897, 92.
13	Inter.	Diorite	Eastern Australia	(Auriferous pyrite.)	———	Igneous	"	1	R. Daintree, *Quar. Jour. Geol. Soc.*, *34*, 187, 433.
14		Diorite porphyry	Loja Province, Ecuador	Trace	———	"	"	1	T. Wolf, *loc. cit.*

TABLE I.—*Continued.*

14	[illegible]	Diorite porphyry	Loja Province, Ecuador	Trace	———			1	T. Wolf, *loc. cit.*

TABLE I.—*Continued.*

No.	Division.	Rock. Name.	Locality.	Contents. Gold.	Contents. Silver.	Weighting. Character of Rock.	Weighting. Primary Gold.	Wt.	Authority.
15	Intermediate.	Andesite	Thames Goldfield, New Zealand	Less than 6.4[6]	———	Igneous	———	3	J. R. Don, *Trans. Am. Inst. Min. Eng., 27* 1898, 648.
16		Tonalite	Charters Towers, Queensland	" 7	———	"	———	3	J. R. Don, *Trans. Am. Inst. Min. Eng., 27* 1898, 638.
17		Syenite pegmatite	Copper Mountain, British Columbia	(Microscopic)	———	"	Positive	3	J. Catherinet, *Eng. and Min. Jour., 79*, 1905, 125.
18		Porphyritic syenite	Kamloops District, British Columbia	"	———	"	Possible.	1	W. F. Ferrier, Geol. Sur. Can., 7, Part B, 1895, 395.
19		Syenite	Candelaria, Nevada	720 mgs.	15,430	"	Probable.	2	L. Wagoner, *loc. cit.*
20		Porphyry	Loja Province, Ecuador	Trace	———	"	Possible.	1	T. Wolf, *loc. cit.*
21		Porphyry	West Kootenay District, British Columbia	———	———	"	"	1	R. W. Brock, *Eng. and Min. Jour., 77*, 1904, 511.
22		Pulaskite	Valkyr Mountains, British Columbia	(Visible.)	———	"	Probable.	2	R. W. Brock, *Eng. and Min. Jour., 77*, 1904, 511.
23		Rhyolitic trachyte	Schemnitz District, Hungary	———	———	"	"	2	von Szabo, cited by W. Möricke, *Zeit. prakt. Geol., 1*, 1893, 143.
24		Biotite-granite	Sonora, Mexico	(Microscopic)	———	"	Positive.	3	G. P. Merrill, *Am. Jour. Sci.*, IV., *1*, 1896, 309.
25		Biotite-granite	Antelope Springs, Colorado	Less than 83 mgs.	———	"	Probable.	2	J. B. Hastings, *Am. Inst. Min. Eng., 39*, 1909, 102.
26		Pegmatite	Mojave, California	332 to 1659	———	"	"	2	C. De Kalb, *Trans. Am. Inst. Min. Eng., 38*, 1908, 312.[8]
27		Granite	Mojave, California	Trace to 33	———	"	"	2	C. De Kalb, *Trans. Am. Inst. Min. Eng., 38*, 1908, 312.[9]
28	Acid.	Granite	Near Valparaiso, Chile	1,000	———	"	Possible.	1	L. Crosnier, *Ann. des Mines*, IV., *19*, 1851, 190.[8]
29		Granite	Andes Mountains, Bolivia	———	———	"	"	1	D. Forbes, *Quar. Jour. Geol. Soc., 17*, 1861, 58.
30		Granite	Eastern Australia	(Auriferous pyrite.)	———	"	"	1	R. Daintree, *loc. cit.*
31		Granite	Carson District, Idaho	Usually at least 415 mgs.	———	"	"	1	A. Simundi, cited by G. F. Becker, 10th census, *13*, Pt. 13, 1880, 54.

TABLE I.—*Continued.*

No.	Division.	Rock. Name.	Locality.	Contents. Gold.	Contents. Silver.	Weighting. Character of Rock.	Weighting. Primary Gold.	Weighting. Wt.	Authority.
32	Acid.	Granite.....	Malay—East Indian tin districts	———	———	Igneous.	Possible.	1	E. Carthaus, *Zeit. prakt. Geol., 3*, 1895, 30.
33		Granite.....	Timbarra, New South Wales	3.406 mgs.	829[10]	"	"	1	G. W. Card, *Rec. Geol. Sur. N. S. W., 4*, 1896, 155.
34		Granite.....	Armagosa, California..	(Visible)	———	May be vein filling	"	0	W. P. Blake, *Trans. Am. Inst., Min. Eng., 26*, 1897, 292.
35		Granite.....	Porcupine Flat, California	104 mgs.	7,660	Igneous.	Probable.	2	L. Wagoner, *loc. cit.*
36		Granite.....	Lake Tenaya, California	137	1,220	"	"	2	L. Wagoner, *loc. cit.*
37		Granite	American River, California	115	940	"	"	2	L. Wagoner, *loc. cit.*
38		Granite.....	Candelaria, Nevada	1,130	5,590	"	"	2	L. Wagoner, *loc. cit.*
39		Granite.....	Lake Shartash, Russia	As much as 1,000	———	"	"	2	Beck-Weed, "The Nature of Ore Deposits," 1905, 305.
40		Quartz porphyry	Loja Province, Ecuador	Trace.	———	"	Possible.	1	T. Wolf, *loc. cit.*
41		Felsite.....	Eastern Australia	(Auriferous pyrite.)	———	"	"	1	R. Daintree, *loc. cit.*
42		Rhyolite.....	Chalone Peaks, California	Trace.	———	"	"	1	H. W. Fairbanks, 12th Rep. State Min. Cal., 1894, 523.
43		Rhyolite	Andacollo, Chile	(Auriferous pyrite.)	———	"	"	1	W. Möricke, *Ber. Naturfor. Ges. Freiburg, 10*, 1898, 22.
44		Rhyolite.....	Guanaco, Chile	———	———	"	Probable.	2	W. Möricke, *Tscher. min. u. pet. Mitth., 12*, 1891, 191.
45		Pitchstone	Guanaco, Chile	(Microscopic)	———	"	Positive.	3	W. Möricke, *Tscher, min. u. pet. Mitth., 12*, 1891, 191.
46		Aplite.....	Antelope Springs, Colorado	41 mgs.	———[11]	"	Probable.	2	J. B. Hastings, *loc. cit.*
47		Eurite.....	Timbarra, New South Wales	11,607	4,974	"	Possible.	1	G. W. Card, *loc. cit.*
48		Eurite.....	5 miles from Timbarra, New South Wales	11,033	3,316[12]	"	"	1	G. W. Card, *loc. cit.*

The irregularity of the gold content of igneous rocks in general, of igneous rocks of the same class, of igneous rocks of the same kind, and even of the same igneous rock, is worthy of special comment. The fact that the contents vary from less than 6 up to 1,659 milligrams per metric ton rendered it necessary in the two preceding paragraphs to qualify the computations of the average gold contents of igneous rocks as a whole and of the grand divisions of igneous rocks considered separately. Wide variations also exist between the amounts of gold in similar rocks from different localities. Amongst the granites containing gold which is probably primary are 6 upon which quantitative determinations have been made. These determinations are: 17, 104, 115, 137, 500 and 1,137 milligrams per metric ton, figures which illustrate how markedly the quantities of gold in similar rocks vary. Moreover, the same rock from the same locality frequently gives returns which vary in just as marked a manner. Thus the monchiquite, number six in the table, varies from a trace to 1,478 milligrams; and the pegmatite, number twenty-seven, from 332 to 1,659 milligrams.

The average silver content of 7 of the 12 rocks used for the

[1] Calculated from sulphides.

[2] Calculated from matte.

[3] Average of 2 samples, 1 containing trace gold.

[4] Silver is average of 2 samples.

[5] Average of 11.825 metric tons in 3 samples assaying 3,750; 18,000 and 27,750 mgrs. respectively.

[6] Two samples, both less than 6.4 mgrs. per m. t.

[7] Three samples, all less than 6.4 mgrs. per m. t.

[8] In a letter to the writer, De Kalb adds: "the pegmatite dikes are unaccompanied by evidence of subsequent mineralization and are certainly free from evidence of hydrothermal activity and I have every reason to believe that the gold contained is primary. It is absolutely certain that there has been no secondary enrichment at the surface."

[9] The presence of gold in the granitic rocks of the Chilean coast has been confirmed by:—Domeyko, "Mineralojia" (1879), 713, and by Schultze, cited by Möricke, Ber. Naturfor. Ges. Freiburg *10*, (1898), 152.

[10] Average of 10 samples, 2 auriferous, one assaying 6,410 mgrs., the other 27,650 mgrs. per m. t.

[11] Average of 4 samples, 1 auriferous.

[12] Average of 4 samples, 1 auriferous.

estimation of gold content is 3,741 milligrams per metric ton. Four of these are basic rocks with an average of 4,092 milligrams and 3 are acid with an average of 3,273 milligrams. The average fineness of the gold in the 4 basic rocks is 23.3 and in the 3 acid 74.5. There are 3 other rocks containing probably primary gold in which both gold and silver have been quantitatively determined, but while in these instances the amounts of gold and silver were considered to be so abnormally high that they were not used in figuring average contents, this does not affect their value in determining average finenesses. If these are included in our calculations, we have 5 basic rocks whose gold has an average fineness of 24.5, 1 intermediate with gold 45.4 fine, and 4 acid whose gold averages 97.9 fine. These results appear to indicate a slight tendency on the part of silver to favor basic rocks.

It is evident that the data concerning the primary gold and silver content of igneous rocks is insufficient to warrant drawing definite conclusions. The evidence, such as it is, tends to show that the igneous rocks contain minute amounts of gold and silver distributed in an extremely irregular manner; that the gold content averages about 62 milligrams per metric ton—equivalent to 0.002 ounce or 4 cents per avoirdupois ton—and the silver content about 3,741 milligrams—equivalent to 0.12 ounce or 6 cents per avoirdupois ton; and that the gold favors neither acid nor basic rocks while the silver manifests a slight partiality for basic rocks.

III. GOLD IN SUB-CRUSTAL WATERS AND IN VEINS.

A table of gold in waters and hydrogenic rocks accompanies this article. The order of tabulation employed was selected to indicate the concentration of gold by the various kinds of waters—numbers one to thirteen being concerned with sub-crustal waters and the succeeding examples with surface waters.

Gold has not been detected in volcanic emanations nor in the products of such emanations. Pneumatolytic deposits frequently contain gold in such quantity that it is of economic importance. From this, it is inferred that plutonic emanations contain gold.

Heated waters rising from great depths are known to contain gold. It has been detected in solution in the deep waters of the Comstock Lode whose temperature varies from 116 to 170 degrees Fahrenheit. Six instances in which deposits formed by other hot springs which are still in existence contain gold are cited in the table. It is inferred that the majority of veins have been formed by such waters.

The vadose circulation of the Comstock Lode contains gold and silver in solution. Numerous instances of gold-bearing lodes which are secondarily enriched near the surface are believed to present proof that gold commonly circulates in vadose waters, and some veins are thought to have been primarily formed by them.[1]

Gold-bearing veins have been found in rocks of all compositions and of all geological ages. Other things being equal, lodes which are mainly the result of cavity-filling will be found by preference in rocks which break easily, producing cavities to be filled—like slates and schists—or which are so hard that when fractured the cavities produced will remain open a long time and give circulating solutions a good chance,—like granites and gneisses. Lodes mainly the result of metasomatism show a preference for easily replaced rocks. Limestone is a favorite on account of its ready solubility, and andesite is a more favorable host than rhyolite because it contains more ferro-magnesian silicates, which are commonly the first minerals to be replaced. Even within a restricted area there is frequently a wide diversity in the character and age of the rocks in which lodes of the precious metals occur. Speaking of the state of Colorado, Rickard says: "Profitable mining for gold and silver has been performed in formations belonging to every division of geological time from the Tertiary to the Archean, and in every kind of rock from the simplest sedimentary to the most complex crystalline."[2]

[1] Interesting papers on the secondary enrichment of gold deposits have recently been published by A. D. Brokaw, *Jour. Geol., 18,* 1910, 321, and W. H. Emmons, *Bull. Amer. Inst. Min. Eng., 46,* 1910, 767.

[2] *Min. and Sci. Press, 100,* 1910, 90.

TABLE II.

GOLD IN WATERS AND AQUEOUS ROCKS.

No.	Substance.	Locality.	Content in Milligrams per M.T.		Authority.
			Gold.	Silver.	
1	Volcanic emanations	General	None observed.		F. C. Lincoln, *Econ. Geol.*, *2*, 1907, 265.
2	Pneumatogenic lodes	Numerous localities	Of economic importance.		
3	Deep water	Comstock Lode, Nevada	0.298	2.92	J. A. Reid, *Bull. Dep. Geol. Univ. Cal.*, *4*, 1905, 189.
4	Pyrite deposited by existing hot springs	Lake Tampo, New Zealand	Trace	———	A. Liversidge, *Jour. and Proc. Roy. Soc., N. S. W. 11*, 1878, 264.
5	Sinter deposited by existing hot spring	Steamboat Springs, Nevada	940[1]	323[1]	G. F. Becker, U. S. G. S. Mon., *13*, 1888, 383–4.
6	Vein filling deposited by existing hot spring	Boulder Montana	768[1]	6,912[1]	W. H. Weed, U. S. G. S. Ann. Rep. *21*, Part II., 1900, 248.
7	Pyrite of veins deposited by existing hot spring	Norris Basin, Yellowstone N. P.	———	———	W. H. Weed, U. S. G. S. Bull., *260*, 1905, 600.
8	Ferruginous tufa, deposited by existing hot spring	Anaconda, Montana	"Often carries" 830 to 2,490	———	W. H. Weed, U. S. G. S. Bull., *260*, 1905, 601.
9	Calcareous tufa, deposited by existing hot spring	Ojo Caliente, New Mexico	42[2]	2,365[2]	W. Lindgren, ECON. GEOL., *5*, 1910, 22.
10	Hydrogenic lodes	Very numerous localities	Of economic importance.		———
11	Vadose water	Australasia	None[3]	———	J. R. Don, *Trans. Am. Inst. Min. Eng.*, 1898, 604.
12	Vadose water	Comstock lode, Nevada	4.1528	188.0912	J. A. Reid, *Bull. Dep. Geol. Univ. Cal.*, *4*, 1905, 189.
13	Secondary enrichments	Very numerous localities	Of economic importance.		———
14	Fresh water	General	None observed.		———
15	Salt water	Nevada Marshes	None	———	J. W. Pack, *Min. and Sci. Press*, *77*, 1898, 154.
16	Salt water	Great Salt Lake, Utah	"Somewhat more than" 32	———	J. W. Pack, *Min. and Sci. Press*, *77*, 1898, 154.

TABLE II.—*Continuek.*

No.	Substance.	Locality.	Content in Milligrams per M.T.		Authority.
			Gold.	Silver.	
17	Sea water	San Francisco Bay	"About" 64[4]	———	J. W. Pack, *Min. and Sci. Press*, 77, 1898, 154.
18	Sea water	San Francisco Coast	"About" 32	———	J. W. Pack, *Min. and Sci. Press*, 77, 1898, 154.
19	Sea water	Ramsey Bay, Isle of Man	"Certainly less than" 64	———	E. Sonstadt, *Chem. News*, 26, 1872, 159–160.
20	Sea water	Kristiania Fjord, Norway	5 to 6	19 to 20	C. A. Munster, cited by F. W. Clarke, U. S. G. S. Bull. 330, 1908, 33.
21	Sea water	Southern Waters, New South Wales	43.3[2]	"Usually"	A. Liversidge, *Jour. Roy. Soc. N. S. W.*, 29, 1895, 343.
22	Sea water	Northern Waters, New South Wales	47.8	64 to 128[6]	A. Liversidge, *Jour. Roy. Soc. N. S. W.*, 29, 1895, 343.
23	Sea water	Coogee Waters, New South Wales	36.4[2]		A. Liversidge, *Jour. Roy. Soc. N. S. W.*, 29, 1895, 346–7.
24	Sea water	Off Jervis Bay, New South Wales	34.8[5]		A. Liversidge, *Jour. Roy. Soc. N. S. W.*, 29, 1895, 348.
25	Sea water	St. Clair Head, New Zealand	4.5[7]	"about" 2.5	J. R. Don, *Trans. Am. Inst. Min. Eng.*, 27, 1898, 613–5.
26	Sea water	San Francisco Bay	12.6[8]	1,50c[8]	L. Wagoner *Trans. Am. Inst. Min. Eng.*, 31, 1902, 806–7.
27	Sea water	Belgian Coast of the North Sea	None	———	P. de Wilde, *Arch. des. Sci. phys. et nat.*, 19, 1905, 569–570.
28	Red Silurian gypsum	Salina, New York	83	———	F. C. Lincoln, this article.
29	Red Mississippian gypsum	Grand Rapids, Michigan	83	———	F. C. Lincoln, this article.
30	Rock salt	Cheshire, England	109	Present	A. Liversidge, *Jour. Chem. Soc.*, 71, 1897, 298.
31	Red rock salt	Cheshire, England	95	"	A. Liversidge, *Jour. Chem. Soc.*, 71, 1897, 298.
32	Red rock salt	Stassfurt, Germany	130	"	A. Liversidge, *Jour. Chem. Soc.*, 71, 1897, 298.
33	Sylvite	Stassfurt, Germany	70	"	A. Liversidge, *Jour. Chem. Soc.*, 71, 1897, 298.
34	Kainite	Stassfurt, Germany	125	"	A. Liversidge, *Jour. Chem. Soc.*, 71, 1897, 298.
35	Carnallite	Stassfurt, Germany	77	"	A. Liversidge, *Jour. Chem. Soc.*, 71, 1897, 298.
36	Carnallite	Stassfurt, Germany	None[9]	———	E. E. Lungwitz, *Eng. and Min. Jour.*, 79, 1905, 669.

TABLE II.—*Continued.*

No.	Substance.	Locality.	Content in Milligrams per M.T.		Authority.
			Gold.	Silver.	
37	Red rock salt	Stassfurt, Germany	Less than 3^{10}	———	K. Friedrich, *Metallurgie*, 3, 1906, 629.
38	White rock salt	Stassfurt, Germany	"	———	K. Friedrich, *Metallurgie*, 3, 1906, 629.
39	Blue rock salt	Stassfurt, Germany	"	———	K. Friedrich, *Metallurgie*, 3, 1906, 629.
40	Sylvite	Stassfurt, Germany	"	———	K. Friedrich, *Metallurgie*, 3, 1906, 629.
41	Boracite	Stassfurt, Germany	"	———	K. Friedrich, *Metallurgie*, 3, 1906, 629.
42	"Older" rock salt	Neindorf, Germany	"	———	K. Friedrich, *Metallurgie*, 3, 1906, 629.
43	Sylvite	Neindorf, Germany	"	———	K. Friedrich, *Metallurgie*, 3, 1906, 629.
44	Carnallite	Neindorf, Germany	"	———	K. Friedrich, *Metallurgie*, 3, 1906, 629.
45	Kainite	Neindorf, Germany	"	———	K. Friedrich, *Metallurgie*, 3, 1906, 629.
46	"Younger" rock salt	Bernburg, Germany	"	———	K. Friedrich, *Metallurgie*, 3, 1906, 629.
47	Kainite	Bernburg, Germany	"	———	K. Friedrich, *Metallurgie*, 3, 1906, 629.
48	Langbeinite	Bernburg, Germany	"	———	K. Friedrich, *Metallurgie*, 3, 1906, 629.
49	Red carnallite	Bernburg, Germany	12	———	K. Friedrich, *Metallurgie*, 3, 1906, 629.
50	Gray carnallite	Bernburg, Germany	Less than 3^{10}	———	K. Friedrich, *Metallurgie*, 3, 1906, 629.
51	Salt clay	Plömnitz, Germany	13	———	K. Friedrich, *Metallurgie*, 3, 1906, 629.
52	Anhydrite	Plömnitz, Germany	7	———	K. Friedrich, *Metallurgie*, 3, 1906, 629.
53	Stinkstone from foot-wall	Heilbronn, Germany	Less than 3^{10}	———	K. Friedrich, *Metallurgie*, 3, 1906, 629.
54	Kieserite with rock salt	Mecklenburg, Germany	"	———	K. Friedrich, *Metallurgie*, 3, 1906, 629.
55	Natural Mother Liquor	Mecklenburg, Germany	No trace	———	K. Friedrich, *Metallurgie*, 3, 1906, 629.

While the lodes of Colorado are distributed in rocks of all save the most recent ages, they were mostly formed at about the same geological time—the latter half of the Tertiary Period. Lindgren[11] has shown that in 4 of the metallogenetic epochs of the Cordilleran Region of North America important gold deposits were formed: the Pre-Cambrian, the late Mesozoic, the early Tertiary and the late Tertiary. For the world as a whole, Maclaren[12] has distinguished 5 aurogenetic epochs: Archean, Pre-Cambrian, Permo-Carboniferous Jurassic and Tertiary. The distinction between the Archean and Pre-Cambrian of Maclaren is that the deposits of the latter epoch are related to basic dikes; and his Jurassic has since been shown to be really much later. The following aurogenetic epochs may therefore be regarded as provisionally established: (5) Late Tertiary, (4) Early Tertiary, (3) Late Mesozoic, (2) Permo-Carboniferous, (1) Pre-Cambrian. Of these epochs, the first and last are the most widespread.

Harker[13] has outlined two petrologic regions, the Atlantic and the Pacific, which show marked chemical and mineralogical differences. The rocks of the Atlantic Region are especially distinguished by their higher content of alkalies and those of the Pacific Region by their higher content of alkaline earths. The Pacific Region embraces all the territory adjacent to the Pacific Coast with the exception of Australia, Tasmania and southern

[1] Average of two analyses.
[2] Average of three analyses.
[3] By a filtration method, reliability questioned by the author himself.
[4] "Largely in a finely divided state."
[5] Average of four analyses.
[6] Determinations "lacking in precision."
[7] Average of six analyses.
[8] Water fresher than normal sea water.
[9] Method not stated.
[10] Reported as an imponderable trace. The author made a series of 40 determinations of gold in salts by a zinc precipitation method whose reliability he questioned himself, and obtained three ponderable quantities of gold:—7, 3 and 3 milligrams. A trace therefore means less than 3 milligrams.
[11] ECON. GEOL. *4*, 1909, 419.
[12] "Gold," 1908, 44.
[13] "The Natural History of Igneous Rocks," 1909, 97.

New Zealand; and in Eurasia it extends as far west as Transylvania. The remainder of the world belongs to the Atlantic Region. The lodes of the Pre-Cambrian and Permo-Carboniferous aurogenetic epochs occur mainly in the Atlantic Region, while those of the three later epochs are found in the Pacific Region.

Auriferous provinces are areas characterized by the occurrence of gold-bearing lodes of somewhat similar character and closely related geological age. Pre-Cambrian auriferous provinces occur in the Appalachians and eastern Canada, in South Dakota, in the Guianas, in Brazil, in South Africa, in India, in Western Australia and in southern New Zealand. The lodes of all these provinces occur principally in schists and are frequently associated with intrusions which include granite, diorite, gabbro and diabase. Auriferous provinces of Permo-Carboniferous age are situated in eastern Australia, in Tasmania, and probably also in the Urals. The gold of these provinces is associated with intrusions of granite, quartz-monzonite or granodiorite, sometimes occurring as deposits within these rocks and sometimes in the neighboring sedimentaries. In late Mesozoic time, batholiths of quartz-monzonitic or granodioritic character were intruded into the sediments of the Pacific Coast of North America from California to Alaska. These masses of igneous rock are fringed with gold-bearing lodes. Intrusions of granodiorite, quartz-monzonite, monzonite, and the porphyritic equivalents of these rocks took place in early Tertiary time from eastern Mexico to British Columbia. Gold lodes occur about the margins of these intrusions, which were smaller than those of the preceding epoch and usually took the form of laccoliths. The late Tertiary auriferous lodes occur in propylitized andesite and to a less extent in rhyolite and other effusives. Provinces of this age and character are known in Chile, Peru, Colombia, Mexico, California, Nevada, Utah, Colorado, Idaho, Unga Island, Unalaska, Japan, Sumatra, Celebes, and Transylvania.

Gold is not positively known to occur in magmatic emanations. Its presence has been proved in both the deep and vadose

circulations of the earth's crust, and we probably owe most of our gold-bearing lodes to the former agency and their enrichment near the surface to the latter. The distribution of veins is only locally influenced by the character and age of the enclosing rocks. Their deposition, however, took place in comparatively restricted geological periods. After extensive gold deposition in Pre-Cambrian time, there was no widespread formation of gold-bearing lodes until the late Tertiary. Veins of similar age and character constitute auriferous provinces, of which there are five groups each belonging to a distinct aurogenetic epoch, and these five groups in turn belong to two great petrologic regions.

IV. GOLD IN SURFACE WATERS AND IN SALTS.

Gold has not been detected in fresh surface waters, but its presence is inferred from its occurrence as a precipitate upon the roots of plants and trees and in certain placer deposits.

Some salt surface waters are free from gold, but its presence has been noted in the waters of Great Salt Lake and numerous investigators have found it in sea water. Eleven determinations of the quantity of gold in sea water are listed in the table of gold in waters and hydrogenic rocks. The average of these is 28 milligrams per metric ton—equivalent to $1\frac{3}{4}$ cents per ton. Malaguti and Durocher found 10 milligrams of silver in sea water. If this is averaged with the 4 determinations cited in the table, a result is obtained of 326 milligrams per metric ton—equivalent to 0.01 ounce per ton.

The writer assayed two samples of red gypsum: one of Salina age from Salina, New York, and the other of Mississippian age from Grand Rapids, Michigan. Four assay tons of each sample were assayed by the ordinary fire method and each returned 5 cents per ton—equivalent to 83 milligrams per metric ton. The litharge employed was too pure to have affected the result. The gold obtained was bright yellow in color and distinctly ponderable.

The average gold content of the 25 salts listed in the table is

32 milligrams per metric ton—equivalent to 2 cents per ton of natural salt or .07 cent per ton of original sea water containing 3.63 per cent. salts.

Friedrich's results considered by themselves appear to indicate an irregular distribution of gold throughout the salts, with concentration in the intercalated clay, and impoverishment of the mother liquor until not a trace of gold remains in it. In this connection, it should be noted that the marls listed in the table of sedimentary rocks contained intercalated beds of salts and were believed by the author to have been enriched by the gold from evaporated sea water. A doubt is cast upon this hypothesis by his statement that those marls are highest in gold which contain the greatest number of grains of quartz. This suggests that the gold accompanies the quartz and is not directly connected with the drying up of an ancient ocean.

When salt is prepared from sea-water artificially, a reversal of the natural process, in so far as the gold is concerned, appears to take place. The precipitated salt is free from gold, which has become concentrated in the mother liquor known as "bittern."[1] This action of gold shows that there is at least one factor in the formation of saline deposits which is not understood and suggests that a new hypothesis as to the origin of certain of these deposits may be necessary.

The extreme irregularity of the gold content of sea water and salts is just as noticeable as it was in the case of the igneous rocks.

V. GOLD IN ORGANISMS AND IN ORGANIC ROCKS.

The absorption of gold from solution by growing plants has been proved experimentally by Egleston,[2] and has been shown to take place in nature by Lungwitz.[3] Egleston watered a growing plant with gold solution and found that while most of the gold was precipitated by the organic matter of the soil, a small amount was taken up by the plant. Lungwitz found that the ashes of

[1] A Liversidge, *Jour. Chem. Soc., 71,* 1897, 299; also J. W. Pack, *Min. and Sci. Press, 77,* 1898, 154.

[2] *Trans. Am. Inst. Min. Eng., 9,* 1881, 642.

[3] Cited by Beck-Weed, "The Nature of Ore Deposits," *2,* 1905, 654.

trees which had grown on the Omai Goldfield contained gold, the proportion present being greater in the upper parts of the trees than in the lower.

Coal is frequently auriferous. From $1 to $5 per ton is reported to be present in the coal mined by the Cambria Coal Company near Newcastle, Wyoming.[1] The ashes of the Pleasant Valley, Utah, and Kemmerer, Wyoming,[2] coals are said to yield an average of from 60 to 80 cents per ton in gold. The ash of the pyritous coal from Batu Belaman, Borneo also contains gold.[3] Since plants absorb gold, it is possible that some of the gold in coal may be derived from them; but vegetable matter and coal are such good precipitants of gold and appear to have precipitated gold so frequently in nature that it seems probable the greater quantity of the gold in coal has been introduced by precipitation from circulating waters.

A specimen of kelp examined by Liversidge contained 1,400 grams of gold per metric ton.[4]

Liversidge also found gold in oyster shells, and 108 milligrams in Chilean niter, a rock of animal origin.

VI. GOLD IN SEDIMENTARY ROCKS.

Shales are the commonest of the sedimentary rocks and their gold content has only been determined in a few instances. The writer therefore made a fire assay of two shales—a gray fossiliferous Cambrian shale from Braintree, Mass., and a black fossiliferous Pennsylvania shale from Pennsylvania. Ten assay tons of each shale were used, each assay ton being fused in a separate crucible and the ten resulting lead buttons scorified together. Silver was added, the resulting buttons were parted, and the gold annealed. A distinct yellow flake was obtained in each case. The amount of gold in both shales was near the limit of sensibility of the balance employed and was estimated to be about $0.005 per ton—equivalent to 8 milligrams per metric ton.

[1] H. M. Chance, *Trans. Am. Inst. Min. Eng., 29,* 1900, 227.
[2] W. P. Jenney, *Trans. Am. Inst. Min. Eng., 33,* 1903, 461.
[3] J. M. Maclaren, "Gold," 1908, 110.
[4] *Jour. Chem. Soc.,* 71, 1897, 299.

In order to determine whether this gold was introduced by the fluxes, blank runs were made. These test runs showed that the fluxes were unusually free from gold, only minute black specks appearing during parting which vanished when annealed. The litharge employed had been selected for its purity from lots purchased by the Montana State School of Mines during a considerable period of years.

Table III. presents occurrences of gold in sedimentary rocks. It is arranged with the coarser rocks first, with the individual rocks of each kind arranged in the order of their geological ages. The average quantity of gold in 4 shales, numbers nineteen to twenty-two, is 14 milligrams per metric ton; and the average in 4 sandstones, numbers fifteen to eighteen, is 22 milligrams. Only one limestone is noted in the table, and that has an abnormally high gold content; but in the table of metamorphic rocks there are 2 marbles, numbers seventeen and eighteen, which have an average content of 7 milligrams. Clarke considers 80 per cent. of the sedimentary rocks to be shales, 15 per cent. sandstones, and 5 per cent. limestones.[1] A computation based on these figures gives the sedimentary rocks an average gold content of 15 milligrams per metric ton—equivalent to 1 cent per ton—which is one-fourth the amount computed for igneous rocks.

The average for shales is twice that for limestones, and the average for sandstones one and one-half times that for shales. Coming to the still coarser rocks, it will be observed that conglomerates are represented in the table to an extent altogether disproportional to their small quantitative occurrence in nature. A general conclusion may be drawn that the coarser the sedimentary rock, the greater will be its gold content. This clearly indicates a tendency of the gold to concentrate by lagging behind during the process of sedimentation.

While the general content of the sedimentary rocks probably varies according to their coarseness, examples of similar rocks from different localities, and of the same rock from the same

[1] Bull. U. S. G. S., *330*, 1908, 31.

TABLE III.

TABLE III.

PRIMARY GOLD IN SEDIMENTARY ROCKS.

No.	Rock.	Locality.	Content in Milligrams per Metric Ton.		Authority.
			Gold.	Silver.	
1	Pre-Cambrian conglomerate	Witwatersrand, South Africa	7,500 to 15,000[1]	———	———
2	Pre-Cambrian conglomerate	Nullagine, Western Australia	18,980[1]	———	J. M. Maclaren, "Gold," 1908, 56.
3	Cambrian conglomerate	Black Hills, South Dakota	As high as 82,950[1]	———	W. B. Devereux, *Amer. Inst. Min. Eng., 10* 1882, 465.
4	Carboniferous conglomerate	Gloucester, England	7,680	———	J. M. Maclaren, "Gold," 1908, 122.
5	Carboniferous conglomerate	Northern Gard, France	Once of economic importance		Simonin, *Comptes Rendus, 66*, 1866, 1342.
6	Permian conglomerate	Tallawang, New South Wales,	1,536 to 23,040	———	J. M. Maclaren, "Gold," 1908, 344.
7	Permian conglomerate	Peak Downs, Queensland	7,680 to 9,216	———	J. M. Maclaren, "Gold," 1908, 340.
8	Jurassic conglomerate	Calaveras County, California	Trace to 597[1]	———	W. Lindgren, *Am. Jour. Sci.*, III., *48*, 1894, 275.
9	Cretaceous conglomerate	Klamath River, California	6,636 to 10,220[1]	———	R. L. Dunn, 12th Rep. State Min. Cal., 1894, 459.
10	Cretaceous conglomerate	Northwestern New South Wales	Nuggets up to 25 ozs.	———	J. M. Maclaren, "Gold," 1908, 343–4.
11	Tertiary conglomerates	Very Numerous Localities	Of economic importance.		———
12	Pleistocene conglomerates	Very Numerous Localities	"	———	———
13	Recent conglomerates	Very Numerous Localities	"	———	———
14	Laterites	Numerous Tropical Localities	"	———	———
15	Sandstone	Colusa County, California	39	540	L. Wagoner, *Trans. Am. Inst. Min. Eng., 31*, 1902, 798.
			39	540	
16	Sandstone	Angel Island, California	24	450	L. Wagoner, *Trans. Am. Inst. Min. Eng., 31*, 1902, 798.
17	Sandstone	San Francisco, California	21	320	L. Wagoner, *Trans. Am. Inst. Min. Eng., 31*, 1902, 798.
18	Ordovician sandstone	Victoria	Less than 6.4[2]	———	J. R. Don, *Trans. Am. Inst. Min. Eng., 27*, 1898, 622–36.
19	Gray Cambrian shale	Bramtree, Massachusetts	About 8	———	F. C. Lincoln, this article.

TABLE III.—*Continued.*

No.	Rock.	Locality.	Content in Milligrams per Metric Ton.		Authority.
			Gold.	Silver.	
20	Ordovician shale.....	Victoria[3]	Less than 6.4[4]	———	J. R. Don, *Trans. Am. Inst. Min. Eng., 27*, 1898, 622–29.
21	Black Pennsylvanian shale.....	Pennsylvania.....	About 8	———	F. C. Lincoln, this article.
22	Benton shale.....	Western Kansas	37[5]	2,820[5]	W. Lindgren, U. S. G. S. Bull., 202, 1902.
23	Columbian clay	Philadelphia.....	817	———	Eckfeldt, *Sci. Am., N. S., 5*, 1861, 247.
24	Recent mud	San Francisco Bay.....	45 to 271	———	L. Wagoner, *Trans. Am. Inst.*
25	Keuper variegated marl	Drill hole, 250.5 m., Rancourt, France.....	4,000	6,000	F. Laur, *Comptes Rendus, 142*, 1906, 1409–13.
26	Muschelkalk sandy marl.....	Drill hole, 382. m., Rancourt, France.....	36,000	245,000	F. Laur, *Comptes Rendus, 142*, 1906, 1409–13.
27	Muschelkalk marl.....	Drill hole, 465 m., Rancourt, France.....	6,000	1,000	F. Laur, *Comptes Rendus, 142*, 1906, 1409–13.
28	Muschelkalk marl.....	Drill hole, 467 m., Rancourt, France	4,000	Trace	F. Laur, *Comptes Rendus, 142*, 1906, 1409–13.
29	Carboniferous limestone	Whalton, Somerset, England..	256[6]	18,730[6]	M. Maclaren, "Gold," 1908, 122.
30	Dredging, 1,091 fathoms deep.....	Off Delaware Bay..... ...	145	1,014	L. Wagoner, *Trans. Am. Inst. Min. Eng., 37*, 1908, 704.
31	Dredging, 49 to 70 fathoms deep.....	Between Chesapeake Bay and Hatteras.....	44	304	L. Wagoner, *Trans. Am. Inst. Min. Eng., 37*, 1908, 704.
32	Dredging, 104 fathoms deep.....	Off Chesapeake Bay.....	15	353	L. Wagoner, *Trans. Am. Inst. Min. Eng., 37*, 1908, 704.
33	Dredging, 677 fathoms deep.....	East of Georges Bank.....	267	1,963	L. Wagoner, *Trans. Am. Inst. Min. Eng., 37*, 1908, 704.
34	Dredging, 1,769 fathoms deep.....	S. E. of Georges Bank.....	125	377	L. Wagoner, *Trans. Am. Inst. Min. Eng., 37*, 1908, 704.
35	Dredging, 990 fathoms deep.....	South of Nantucket.....	66	414	L. Wagoner, *Trans. Am. Inst. Min. Eng., 37*, 1908, 704

locality show extremely wide variations in gold content just as in the case of igneous rocks and natural salts. A still further irregularity has been observed in connection with sedimentary rocks:—the same identical sample thoroughly mixed and assayed at different times with all possible precautions does not always give the same return. In the case of the Benton shale, number twenty-two on the table, this peculiarity was plainly shown.

The geographical distribution of placers naturally corresponds rather closely with the distribution of the auriferous provinces from which they have evidently been derived. The distribution of the more important placers in geological time is also closely related to that of the auriferous provinces, the placers having been formed just subsequent to each period of gold deposition. After the first aurogenetic epoch, the gold-bearing conglomerates of the Witwatersrand, South Africa, and of Nullagine, Western Australia, and the auriferous sandstone of the Black Hills, South Dakota, were formed; after the second epoch, the conglomerates of Tallawang, New South Wales and of Peak Downs, Queensland; after the third, the conglomerate of the Klamath River, Cal.; and after the two Tertiary aurogenetic epochs an enormous number of placers distributed throughout the Pacific Region. These facts indicate that times of active lode formation have been accompanied or followed by elevations of the land and the consequent formation of placers. The paucity of Cambrian placers is noteworthy, since the Pre-Cambrian was an extremely active period of gold lode formation. Even the three instances cited above are not unexceptionable; the gold of the Nullagine conglomerate has suffered marked re-arrangement, if, indeed, it is not secondary; some authors consider the gold of the Witwatersrand to be secondary; while the economic value of the Potsdam

[1] Gold possibly of secondary origin.

[2] 14 determinations, all less than 6.4 mgrs.

[3] Called "slate" by the author. Called shale in this table because interbedded with the sandstone cited as number 18.

[4] 4 determinations, all less than 6.4 mgrs.

[5] Average of 19 samples. Different assays of the same sample would give a ponderable result in one instance and not even a trace in another.

[6] Average of two assays. Fluxes may not have been pure.

conglomerate of the Black Hills is held to be almost entirely due to secondary impregnation.

Residual rocks also form some important placers. The more valuable deposits of this class are laterites—the residual rocks of warm climates in whose formation the chemical action of surface waters has played a more or less important part. This leads to the inference that the gold in such rocks has been concentrated by chemical as well as by mechanical means; so that geneticaliy residual placers form an intermediate group between placers and veins.

VII. GOLD IN METAMORPHIC ROCKS.

In the earlier stages of metamorphism, the original source of the gold is sometimes clear. When metamorphism is complete and the gold has become one of the primary minerals of the metamorphic rock, it is only possible to hazard a guess as to what its original nature may have been.

Table IV. contains eighteen examples of such primary gold in metamorphic rocks. Two of the cases cited are of special interest because their primary gold has been the object of mining operations. The quartz-diorite gneiss of the Ayrshire Mine in Mashonaland is being successfully mined at the present time and the granitelle gneiss of the Campanha and São Gonçalo Districts in southern Minas Geraes, Brazil, was formerly worked upon an extended scale. In other instances, the primary gold of metamorphic rocks has supplied the gold of important placer deposits. Such is the case in British Guiana, French Guiana and Madagascar.

VIII. CERTAIN HYPOTHETICAL CONSIDERATIONS.

The average quantity of gold in igneous rocks, as found in section II above, was 62 milligrams per metric ton. The average quantity of gold found for the sedimentary rocks—15 milligrams per metric ton, and for the sea—28 milligrams per metric ton, may be used as a check upon this figure if it is assumed that the salts in the sea have been derived by the destruction of igneous rocks. For in that case the total amount of gold in the sedimen-

TABLE IV.

TABLE IV.

PRIMARY GOLD IN METAMORPHIC ROCKS.

No.	Rock.	Locality.	Content in Milligrams per Metric Ton.		Authority.
			Gold.	Silver.	
1	Serpentine	Urals, Russia	(Visible)	——	J. Morozewics, *Mém. Comité Géol., N. S., 8,* 1903, 40.
2	Serpentine	Northern New Caledonia	7,000 to 8,000	——	A. Lacroix, *Mineralogie de la France, 2,* 1897, 425.
3	Amphibolite	British Guiana	192 to 3,072	——	J. B. Harrison, "Goldfields of British Guiana, 1908, 208.
4	Epidiorite	British Guiana			
5	Hornblende schist	British Guiana			
6	Hornblende schist	Roche Cr., Awa, French Guiana	2,000	6,000	E. D. Levat, *Ann. des Mines,* IX, *13,* 1898, 416.
7	Hornblende schist	Pichevin Cr., Awa, French Guiana	1,500	2,000	E. D. Levat, *Ann. des Mines,* IX, *13,* 1898, 416.
8	Hornblende schist	Maripa	24,000 (Visible)	4,000	E. D. Levat, *Ann. des Mines,* IX, *13,* 1898, 416.
9	Pyroxene schist	Ambositra, Madagascar	(Visible)	——	A. Lacroix, cited by J. M. Maclaren, "Gold," 1908, 429.
10	Quartz-diorite gneiss	Ayrshire Mine, Mashonaland	23,000 (Visible)	——	J. E. Spurr, *Eng. and Min. Jour., 76,* 1903, 500.
11	Biotite gneiss	Mandraty River, Madagascar	(Microscopic)	——	A. Lacriox, *Comptes Rendus, 132,* 1901, 181.
12	Gneiss	Western Ontario	Trace to 830	——	G. A. Young, Rep. Geol. Sur. Canada, *1085,* 1909, 87.
13	Ferruginous gneiss [1]	Mundi Mundi, New South Wales	204,800 (Microscopic)	——	Jacquet, *Mem. Geol. Sur. N. S. W., 5,* 1894, 133.
14	Granitelle gneiss	Southern Minas Geraes, Brazil	5,000 to 10,000	——	A. O. Derby, *Am. Inst. Min. Eng., 33,* 1903, 282.
15	Granulite	Near Nantes, France	(Visible)	——	A. Lacroix, *Mineralogie de la France, 2,* 1896, 419-20.
16	Magnetite-b'g quartzite	Mandraty River, Madagascar	(Microscopic)	——	A. Lacroix, *Comptes Rendus, 132,* 1901, 181.
17	Marble	Tuolumne County, California	5	212	L. Wagoner, *Trans. Am. Inst. Min. Eng., 31,* 1902, 798.
18	Marble	Carrara, Italy	8.63	201	L. Wagoner, *Trans. Am. Inst. Min. Eng., 31,* 1902, 798.

[1] "A ferruginous felspathic rock" which from the published figure appearsto be a gneiss.

tary rocks plus the total amount in the sea and divided by the weight of the sedimentary rocks plus the weight of the sea salts would give the amount originally present in the igneous rock. Using Clarke's figures[1] for the weights of sedimentary rocks, the sea, and sea salts, this computation gives a result of 55 milligrams per metric ton, a figure entirely in accord with the 62 milligrams per metric ton obtained by the other method. The evidence at present available tends, therefore, to show that the average gold content of the igneous rocks is about 6 parts per hundred million—equivalent to 3½ cents per ton. Vogt[2] has estimated the gold content of the earth's crust to lie in the tenth or eleventh decimal place: while DeLaunay[3] has placed it in the eighth or ninth place. The writer's estimate is in accord with DeLaunay's higher figure.

It has been shown that the available data present no evidence from which one may reasonably adduce a tendency of the gold of igneous rocks to segregate in the more acid or the more basic rocks. There is another line of reasoning tending to confirm this conclusion. It came as a positive surprise to the writer to find how few were the authentic cases on record of the occurrence of primary gold in igneous rocks. If any marked magmatic segregation of gold had taken place, it would seem that examples would be more common, or at least that important placed deposits would have been formed from the primary gold of igneous rocks. Let us put these ideas in a more concrete form. Three metals are known to be concentrated into ores by magmatic segregation—iron, nickel and chromium. Kemp[4] has shown that the approximate amounts of concentration which these metals must undergo to form ores are respectively 10, 250 and 4,000 into 1. Such concentrations applied to a magmatic content of 3½ cents in gold per ton would produce rock assaying $0.35, $8.75 and $144.00 per ton. The two latter rocks would constitute gold ores. No such ores have been found. If there were

[1] Bull. U. S. G. S., *330*, 1908, 31.
[2] *Zeit. für prakt. Geol., 6*, 1898, 324.
[3] "L'Or dans le Monde," 1907, 81.
[4] ECON. GEOL., *1*, 1906, 215.

any considerable bodies of igneous rock assaying 35 cents per ton, some of them would almost certainly have produced placers of economic importance. The gold in the fabulously rich Klondike District only represented a saving of about 2 cents per ton of rock eroded.[1] Yet no placers whose gold has been derived from the primary contents of igneous rocks have proved of economic value.[2] On these grounds, it would seem unsafe in the present state of our knowledge to assume any considerable magmatic segregation of gold in igneous rocks.

The source of gold in placers has been satisfactorily explained, but the origin of that in veins is not so well understood. Some of the facts presented in preceding sections seem to have a direct bearing upon the source of vein gold. They are:—(1) Gold has not been identified in volcanic emanations and its presence in plutonic emanations has only been inferred. (2) Gold has been identified in the circulating waters of the earth's crust. (3) There are an immense number of economically valuable deposits of primary gold in geologically young conglomerates. (4) There are several in geologically old conglomerates. (5) There are two known cases in metamorphic rocks. (6) There are none in igneous rocks.

Presented in this order the evidence strongly suggests that the gold of many lodes may have been derived by circulating waters from buried placer deposits. Kemp[3] has shown that the leaching of compact subterranean masses of rock to form ores is a very difficult and improbable process, while the leaching of open-textured clastic rocks is comparatively easy. Maclaren[4] has pointed out that ancient placers may be one source of gold in lodes, but he believes that the principal source is emanations from intrusive magmas. The writer's own conclusion is that the sources of lode gold in the order of their importance are

[1] F. C. Lincoln, *Eng. and Min. Jour.*, *91*, 1911, 470.

[2] J. B. Hastings in *Trans. Am. Inst. Min. Eng.*, *39*, 1909, 97–103, describes an economically valueless deposit of auriferous sands whose gold content has been derived by concentration from the primary gold in a biotite-granite.

[3] Econ. Geol., *1*, 1906, 228.

[4] "Gold," 1908, 106 and 103.

probably as follows: (1) Depressed beds of open-textured sedimentary rocks, (2) depressed beds of open-textured tufaceous rocks, (3) fractured older lodes, (4) fractured compact igneous rocks, and (5) fractured compact sedimentary rocks.

A further suggestion of interest is also made by Maclaren.[1] He thinks that the Tertiary andesitic goldfields may have obtained their gold from underlying Pre-Cambrian deposits, either by fusion of these deposits to form the andesites or by the leaching of them by magmatic emanations from the andesites. According to the writer's hypothesis, the Tertiary lodes owe their gold mainly to the leaching of Pre-Cambrian placers by magmatic or meteoric waters put in circulation by the intrusion of the andesites.

The geologic history of gold may be briefly summed up as follows. The gold in an igneous magma is distributed approximately evenly throughout its mass and but trifling rearrangement takes place during cooling. Important concentration begins with the destruction of the igneous rock by erosion, when coarse-textured rocks with a higher gold content and fine-textured rocks with a lower gold content are formed. Such of these rocks as reach the sea yield at least a portion of their gold to solution in the sea water. The sea is an agent of dispersion. Gold is slowly precipitated from sea water by plants and animals and perhaps under some conditions by organic matter. The sedimentary rocks depressed and buried by later sediments change to metamorphic rocks and eventually, perhaps, back into igneous rocks in which the gold again becomes evenly dispersed. Although of great economic interest, lodes are quantitatively unimportant and so were not mentioned in the cycle described above. They are formed whenever circulating waters act as solvents in one part of their course and precipitants in another. This may first occur before the complete solidification of the magma when emanations from the still liquid portion traverse fissures in the newly formed igneous rock removing part of its gold content to be precipitated in some favorable location. From this period until the refusion

[1] "Gold," 1908, 61.

of the sediments there are frequent opportunities for the leaching of the rocks. The most readily leached rocks are the open-textured clastic rocks, and of these sedimentary rocks of continental origin usually have a higher gold content than tuffs and so are probably the most important source of vein gold. The normal cycle is commonly varied by re-elevations of the depressed rocks and erosions of the derived sedimentary and metamorphic rocks as well as of the original igneous rock. Veins are present in all these rocks and their contributions are the chief source of the gold in many placers.

PART TWO: ASSOCIATIONS OF GOLD WITH MINERALS.

I. GOLD MINERALS.

Gold occurs in nature chiefly as native gold. To a lesser but still important extent it is found as an essential constituent of certain tellurides—calaverite, krennerite, sylvanite, petzite and nagyagite. The silver telluride, hessite, usually contains some gold which is probably present in chemical combination, since the mineral is isomorphous with petzite.

Gold selenide may be artificially prepared in the form of a black powder. The close chemical relationship existing between selenium and tellurium suggests that natural gold selenides may exist analogous to the gold tellurides, but none have yet been identified. According to Truscott,[1] the gold of the Redjang-Lebong Mine in Sumatra "occurs so finely disseminated throughout the mass that it is rarely visible, even in those pieces which assay tens of ounces per ton and even with the help of a microscope." The bullion from this mine contains over 4 per cent. selenium, and Ivey[2] says, "a considerable proportion of silver and possibly some gold may exist as selenide." This possibility is confirmed by the writer's investigations. Polished surfaces of rich gold ore from Sumatra failed to show the presence of native gold under a magnification of 400 diameters. Umpleby's work on the gold ores of the Republic District, Ferry

[1] *Trans. Inst. Min. and Met., 10,* 1902, 53.
[2] *Trans. Inst. Min. and Met., 12,* 1903, 341.

County, Washington, has led him to conclude that about 40 per cent. of the gold is free and the remainder combined, probably as a gold-silver selenide.[1] In both the Redjang-Lebong mine and the Republic district, the gold may be present as native gold in an extremely fine state of division. This hypothesis is favored by the fact that there are two localities where native gold and seleniferous compounds are known to occur intergrown. At the Falun mine, Sweden,[2] native gold is intimately associated with seleniferous galenite and bismuthinite, while at Goldfield, Nev.,[3] it occurs intergrown with a selenium mineral, goldfieldite.[4] It is therefore unnecessary to assume that when gold occurs in an unrecognized form in a seleniferous ore it probably forms a compound with tellurium, and the burden of evidence seems rather against than for the existence of a gold selenide.

A number of gold sulphides may be prepared in the laboratory, but none of these are known in nature. They may exist in small amount intermixed with base sulphides, but as yet no reliable method has been devised by which they may be separated and detected if present. Atherton[5] thought he had proved the presence of gold sulphide in the ores of the Deep Creek Mines of New South Wales by showing that a considerable proportion of their gold was soluble in sodium polysulphide, while Williams[6] thought he had proved it for the Stoughton Mine in Colorado by showing some of its gold to be soluble in ammonium sulphide; but the gold in these and other similar cases may be present in the native state since several investigators have proved that metallic gold is soluble in alkaline sulphide solutions.[7]

Several natural alloys of gold exist. The most important of

[1] Washington Geol. Sur., Bull. *1*, 1910, 37.
[2] J. M. Maclaren, "Gold," 1908, 197.
[3] F. L. Ransome, U. S. G. S. Prof. Paper, *66*, 1909.
[4] Selenium also occurs associated with the gold ores of Waihi and Great Barrier, New Zealand, with the silver-gold ores of Tonopah, Nevada, and Guanajuato, Mexico, and with the silver ores of several South American mining camps. See J. E. Spurr, U. S. G. S. Prof. Paper, *42*, 1905, 281 and 285.
[5] *Eng. and Min. Jour.*, *52*, 1891, 698.
[6] *Eng. and Min. Jour.*, *53*, 1892, 451.
[7] See, for example, T. Egleston, *Trans. Amer. Inst. Min. Eng.*, *9*, 1881, 640.

these is the alloy with silver. Native gold and native silver are isomorphous, and the natural gold-silver alloys range from gold with a minute amount of silver to silver with a minute amount of gold, the alloys in the middle of the series being frequently called "electrum." The rarer natural alloys of gold are natural amalgam, maldonite or bismuth-gold and porpezite or palladium-gold.

Other auriferous minerals may owe their gold content to the mechanical admixture of small amounts of the minerals noted above.

II. IDENTIFICATION OF GOLD MINERALS.

It has already been remarked that the color and luster of native gold are so distinctive as to render its identification a simple matter in most instances. Chalcopyrite normally has the same color, and certain other sulphides—notably pyrite—are sometimes tarnished to it; but their luster is different. Upon this the old sight test for small specks of gold is based. The specimen is rotated and the appearance of the fleck of doubtful mineral observed in different lights. The appearance of gold does not change during this test, while that of the other minerals varies to a greater or lesser degree. When readily recognizable gold grains exist in a specimen, it is usually safe to consider all smaller yellow grains down to the limit of vision occurring in the same specimen to be gold, but the eye cannot certainly distinguish particles of gold with diameters less than about 0.5 millimeter without the aid of a microscope. Gold crystals slightly larger than this and so definitely identifiable by the naked eye are shown in Fig. 32.

The lower limit of microscopic perception is 0.1 micron (a "micron" being the thousandth part of a millimeter), when a photographic plate is employed. Unaided by photography, the eye is unable to perceive particles unless their diameters are several times this, and it is not until gold particles reach diameters in excess of the 1 micron that their color and luster become ap-

parent. According to Liversidge,[1] 1/5,000,000,000 grain of gold leaf is visible under the microscope.

Since gold is opaque, its color and luster can only be observed by reflected light. Nevertheless, if the major portion of the minerals in a specimen are translucent, it may best be studied in thin section. When viewed in thin section by transmitted light gold appears dark like all opaque minerals. The yellow color and metallic luster may be brought out by shading the mirror of

FIG. 32. Native Gold from the Homestake Mine, South Dakota.

the microscope and permitting light to fall upon the slide from above. Yellow specks not certainly identified as gold may be tested in the following manner. The slide is gently heated and the cover glass removed. The Canada balsam is removed from the vicinity of the yellow fleck by means of a little turpentine. A drop of hot nitric acid is now placed upon the doubtful particle. Under this test gold remains bright and unchanged while chalcopyrite and other yellow, opaque minerals are attacked.

[1] *Quar. Jour. Roy. Soc. N. S. W.*, *29*, 1895, 366.

When the majority of minerals in an auriferous specimen are opaque, it should be studied on polished surfaces prepared according to Campbell's method.[1] On such surfaces viewed by reflected light the gold appears as a yellow metallic mineral devoid of structure. When the silver content of the gold is small, it has a deep yellow color which is only duplicated, in so far as the writer is aware, by the mineral chalcopyrite. The larger grains of chalcopyrite, however, exhibit a rough surface, due to the presence of a structure resembling a thick growth of moss, which is never observed on grains of gold. Smaller particles of chalcopyrite might readily be mistaken for gold. The best test for gold on a polished surface is to rub the surface with a drop of mercury on a chamois pad. The mercury becomes finely divided and amalgamates even the most minute gold particles so that when they are again examined beneath the microscope their color is found to have been changed from yellow to a brilliant white. After the chamois pad has been used a few times, it retains enough finely divided mercury so that it is unnecessary to add more for a considerable length of time.

When the silver content of the native gold becomes higher, its color becomes paler and it may appear like the paler yellow metallic minerals, pyrite, marcasite, pyrrhotite, sylvanite and calaverite. Pyrite and marcasite have slightly rough surfaces due to mossy structure on a smaller scale than that of chalcopyrite, while pyrrhotite has an extremely rough surface owing to the development of very coarse mossy structure. Moreover, pyrrhotite has a decided pinkish tinge, and pyrite and marcasite are blackened by covering them for one minute with a drop of cold, 1 :2, or stronger, nitric acid. Sylvanite and calaverite have smooth surfaces like gold and are indistinguishable in appearance, but treatment with cold dilute nitric acid for 1 minute tarnishes them to a bronze color. None of the yellow minerals save gold are whitened by the amalgamation test.

Sylvanite and calaverite are said at times to have a tin white color, although I have not observed this under the microscope.

[1] Economic Geology, *1*, 1906, 751.

The bronze tarnish with dilute nitric acid distinguishes them from all other gray metallic minerals tested by the writer, but no means of distinguishing them apart has been devised. Petzite and hessite are also tarnished by 1 : 2 nitric acid but the tarnish is a mixture of brown and blue. They also appear to be indistinguishable from one another by any simple method. Galenite, which is tarnished in an exactly similar manner can, however, be distinguished from hessite and petzite because it is colored in one minute by 1 : 4 nitric acid while petzite and hessite are unaffected by acid of that strength. None of the other common gray metallic minerals investigated by the writer are affected by cold 1 : 2 nitric acid in one minute. Nagyagite is unaffected by 1 : 2 cold nitric acid in one minute but is tarnished gray by 1 : 1 acid.[1] A summary of the tests just described is given in Table V.[2]

When a small amount of gold chloride is melted into a lead-potash glass it dissolves, leaving a clear white glass slightly streaked with yellow. Upon re-heating this glass till it softens, a ruby color is developed and the product is known as "gold ruby glass." Its red color has been shown to be due to the presence of minute gold particles which in the best quality of ruby glass are too small to be seen beneath the most powerful microscope of the ordinary type, but whose presence is made sensible by the ultramicroscope. In this instrument the glass is observed from above by means of a powerful microscope while it is lighted by a strong beam of light thrown from one side and in a direction at right angles to the axis of the microscope. Under these conditions, while the outlines of the gold particles can not be seen, yet their presence is made manifest by the appearance of numerous star-like rays of light reflected from them. The number of these rays in a known volume may be counted, and since the gold content of the glass is known, the average

[1] To etch the minerals, stronger acid than that which tarnishes them should be used.

[2] Most of the mineral specimens used for this work were selected from the collections of Columbia University by Professor Moses for whose kind assistance the writer desires to express his thanks. Unfortunately no specimen of krennerite could be procured for testing purposes.

TABLE V.

IDENTIFICATION OF GOLD MINERALS ON POLISHED SURFACES.

Mineral.	Color.	Texture.	Effect of Treatment with:				
			HNO_3, 1:1.	1:2.	1:4.	HCl, 1:1.	Hg.
Native Gold	Deep yellow.	Smooth.	0	0	0	0	Amalgamation.
Chalcopyrite	Deep yellow.	Rough.	0	0	0	0	0
Pyrite	Pale yellow.	Slightly rough.	Black tarnish.	Black tarnish.	0	0	0
Marcasite	Pale yellow.	Slightly rough.	Black tarnish.	Black tarnish.	0	0	0
Pyrrhotite	Pale reddish yellow.	Very rough.	0	0	0	0	0
Calaverite	Pale yellow.	Smooth.	Bronze tarnish.	Bronze tarnish.	0	0	0
Sylvanite	Pale yellow.	Smooth.	Bronze tarnish.	Bronze tarnish.	0	0	0
Nagyagite	White.	Smooth.	Gray tarnish.	0	0	0	0
Petzite	White.	Smooth.	Brown and blue tarnish.	Brown and blue tarnish.	0	Gray tarnish.	0
Hessite	White.	Smooth.	Brown and blue tarnish.	Brown and blue tarnish.	0	Gray tarnish.	0
Galenite	White.	Smooth.	Brown and blue tarnish	Brown and blue tarnish	Brown and blue tarnish.	Gray tarnish.	0
Other common white minerals		—	—	0	0	—	—

weight of the individual ultramicroscopic gold particles may be estimated. As the shape of these minute specks is unknown, their diameters cannot be exactly estimated, but it has been figured that the smallest have diameters between 4 and 7 thousandths of a micron,[1] or about one hundredth as great as can be observed with the ordinary microscope.

Gold particles of even smaller size are known to exist in gold ruby glass. If white auriferous glass is carefully heated on one side, a ruby color may be developed which fades out and disappears before the other side is reached. When such a piece of glass is examined under the ultramicroscope it is found that the size of the gold particles decreases rather regularly toward the colorless part and that the glass is still red beyond the point where the last visible rays are thrown out by ultramicroscopic gold particles. Since the ruby color is due to gold particles, it is evident that gold particles may exist in ruby glass too small to emit rays that can be seen by the ultramicroscope.

It is possible that gold particles of ultra-and sub-microscopic sizes exist in nature. Quartz assaying high in gold is often found to contain no visible native gold even when examined under the microscope. Whether the gold in such quartz is in solid solution or in minute particles is, for the present at least, impossible of determination; for even if the presence of ultramicroscopic particles is shown, there is no method by which the composition of those particles can be determined, for a red color may be produced by other ultramicroscopic substances such as copper. Certain occurrences are highly suggestive, however. Thus the Ragged Top ore, previously referred to as one impossible of concentration by panning, is of a dull wine color and although running from $100 to more than $200 per ton does not show a trace of free gold. Tests on roasted and unroasted material are said to give practically identical results. Chance[2] concludes that the gold exists in some unknown condition or combined with silica in the form of a compound not appreciably

[1] Siedentopf and Zsigmondy, *Drude's Annal.*, *10*, 1903, 30–39.
[2] *Trans. Amer. Inst. Min. Eng.*, *29*, 1900, 228.

heavier and possibly even lighter than the gangue. All of the peculiarities of this ore are explicable upon the hypothesis that the gold is present in a fine state of division comparable with that in which it exists in ruby glass.

The writer performed a series of experiments upon ruby glass for the purpose of ascertaining to what degree gold in so fine a state as that in the glass would be affected by amalgamation and cyanidation. White auriferous glass[1] was rubified by heating it in a muffle until it melted. The product obtained was not of a clear ruby color but had a milky cloudiness, and it is therefore probable that some of the gold was precipitated in larger particles than occur in a good grade of ruby glass. The glass was all crushed to pass a 40-mesh screen. It was then thoroughly mixed and one half set aside for amalgamation and cyanide tests. The remainder was all crushed to pass a 100-mesh screen and after a thorough mixing one half was reserved for assay. The other half of the 100-mesh material was then crushed to pass a 200-mesh screen, making "slime" for a second cyanide test. The amalgamation test was made by shaking one assay ton of 40-mesh glass over an amalgamated plate in a little water for one-half hour. The cyanide tests were made by treating two assay tons of both the 40-mesh and the 200-mesh ruby glass. Each size was placed in a glass bottle and covered with 120 cubic centimeters of 0.1 per cent. potassium cyanide solution. The bottles were shaken at intervals for 24 hours and then the contents were filtered and washed. Assays were then made with the following results:

No.	Material.	Ounces Gold Per Ton.
1	100-mesh ruby glass.	2.93
2	100-mesh ruby glass.	2.97
3	40-mesh after amalgamation	2.72
4	40-mesh after cyanidation	2.25
5	200-mesh after cyanidation	2.44

These returns indicated that the gold content of the 40-mesh and that of the 200-mesh could not be like the 100-mesh in spite of

[1] This glass was obtained through the kindness of Dr. P. C. McIlhiney, consulting engineer, of New York City.

the precautions taken to secure material of uniform grade. Fortunately enough material remained to make assays of the original 40-mesh and 200-mesh glass, and these gave the following results:

No.	Material.	Ounces Gold Per Ton.
6	40-mesh ruby glass	2.68
7	200-mesh ruby glass	2.98

It should be noted that the bright pink color of the ground glass underwent no perceptible diminution as a result of any of the tests.

These results show that the gold was not evenly distributed throughout the glass, since careful assays of the same sample varied by 0.04 ounce per ton. No gold was amalgamated. 16 per cent. of the gold content was extracted by cyanidation of the 40-mesh ruby glass and 18 per cent. by the cyanidation of the 200-mesh glass or "slime." Since about three times the surface exposed at 40-mesh is exposed at 200-mesh, one might expect the extraction by cyanide to be tripled. As a possible explanation of what actually did occur, it may be suggested that about 15 per cent. of the gold in the glass experimented upon was so coarse that it was freed from the glass when that was ground to 40-mesh, while the remainder was considerably finer and was not set free to any extent upon grinding to 200-mesh. About 1 per cent. of the extraction at 40-mesh came from the surface of the gold particles in this case, and about 3 per cent. of the extraction at 200-mesh. In any event, the tests proved that gold in a metallic state may be so finely divided as not to be affected by ordinary amalgamation processes and only to a slight extent to be extracted by cyanidation even of the slimed material.

III. GOLD AND THE MINERALS OF ROCK.

Primary gold has been observed microscopically and described in detail in three igneous rocks—a pitchstone from Guanaco, Chile, a biotite-granite from Sonora, Mexico, and a syenite pegmatite from Copper Mountain, British Columbia.[1] In all three

[1] Numbers 18, 25 and 46 in the table of primary gold in igneous rocks.

instances, the gold particles are distributed with considerable evenness throughout the mass of the rock and show no decided preference for one or another of the component minerals. In the pitchstone, fine, hackly, crystal skeletons of gold occur arranged in lines equally distributed through the glassy groundmass, the spherulites, and the orthoclase and plagioclase phenocrysts. In the biotite-granite beautifully perfect arborescent and extremely thin platy forms occur associated with the mica or imbedded in the quartz granules and feldspars. In the syenite pegmatite, flakes of gold occur in the orthoclase and in the bornite which in this instance is a primary constituent of the rock.

Owing to its high specific gravity and slight solubility, gold tends to segregate in sedimentary rocks with other heavy or difficultly soluble minerals. Of these, magnetite is the commonest associate of gold; after which come ilmenite, garnet, rutile, zircon and pyrite; and less commonly other sulphides, barite, wolframite, scheelite, platinum, diamond, and so on through a long list of mineral species. What minerals will accompany placer gold depends upon what heavy and relatively indestructible minerals were present in the district whose degradation formed the placer, and to a lesser but important degree upon the nature of the degradation. At times, even magnetite may fail to accompany the gold.

Primary gold has been observed microscopically and described in detail in three metamorphic rocks—a quartz-diorite gneiss from Mashonaland, Africa, and a biotite-gneiss and a magnetite-bearing quartzite, both from the Mandraty River, Madagascar.[1] In the first and last rocks, the gold, while occurring in all components, is most intimately associated with the magnetite. In the biotite-gneiss, magnetite is wanting and the gold is distributed in grains and sharp crystals of all sizes from those visible to the naked eye to those less than a micron in diameter arranged in straight lines and curves like liquid inclusions. This arrangement of the gold is similar to that in the pitchstone described above. None of the igneous rocks described contained more

[1] Numbers 10, 11 and 16 in the table of primary gold in metamorphic rocks.

than a trace of magnetite. It would be interesting to know whether the primary gold in eruptive rocks containing magnetite is as closely associated with the magnetite as it appears to be in metamorphic rocks.

IV. GOLD AND THE MINERALS OF VEINS.

Table VI. on the associations of native gold with the minerals of veins was prepared by collecting and analyzing 585 recorded occurrences of gold in veins. The list is by no means exhaustive, but is sufficiently large to form a basis for generalizations. Of the examples used, 160 were from the United States, 42 from the remainder of North America, 46 from South America, 45 from Asia, 25 from Africa and 75 from Australasia. Fifty-seven minerals mentioned but once and then not as intimately associated with gold were excluded from the table. All the cases in which a given mineral was mentioned as occurring in a gold-bearing vein are given in the column headed "Total." In many instances, the record was very incomplete in so far as the associations of the gold were concerned, and no further analysis was possible, but in the cases recorded in the "Explicit" column sufficient details were given to permit of assignment to the five remaining columns. Thus the gold may occur "intergrown" with the mineral, "disseminated" through it, "upon" or "in" the mineral, or simply in the same vein "with" it.

The most common metallic minerals occurring with gold in veins, in the order of their numerical importance are—pyrite, galenite, chalcopyrite, sphalerite, arsenopyrite, stibnite, tetrahedrite, argentite, pyrrhotite and silver. The non-metallic minerals are quartz, calcite and barite.

It is of chief interest to both miner and scientist to know with what minerals the gold is intimately associated. When gold is intergrown with a mineral it is evidently contemporaneous, and it is probable that in the majority of cases when gold is disseminated through a mineral it is also contemporaneous. We may therefore get a fair idea of the tendency of a given mineral to be deposited at the same time as gold by adding together the

TABLE VI.

TABLE VI.

ASSOCIATIONS OF NATIVE GOLD WITH VEIN MINERALS.

Minerals of	No.	Name.	Composition.	Total.	Ex-plicit.	Inter-grown.	Dissem-inated.	Upon.	In.	With.
Antimony	1	Antinomy	Sb	4	3	—	—	—	—	3
	2	Stibnite	Sb_2S_3	59	28	4	7	1	—	16
		(Also nos. 25, 27, 28, 30, 54, 55, 95, 96, 97 and 98.)								
Arsenic	3	Arsenic	As	8	4	—	1	1	1	1
	4	Orpiment	As_2S_3	3	0	—	—	—	—	—
	5	Realgar	AsS	8	4	—	1	—	—	3
		(Also nos. 24, 25, 26, 30, 43, 50, 69, 99.)								
Barium	6	Barite	$BaSO_4$	37	24	7	1	3	—	13
Bismuth	7	Bismuth	Bi	7	2	1	1	—	—	—
	8	Bismuthinite	Bi_2S_3	7	5	3	1	—	—	1
	9	Tetradymite	$Bi_2(TeS)_3$	8	2	2	—	—	—	—
	10	Bismite	Bi_2O_3	2	2	—	—	—	—	2
		(Also nos. 20 and 29.)								
Calcium	11	Calcite	$CaCO_3$	135	72	12	7	4	—	49
	12	Dolomite	$(CaMg)CO_3$	21	16	—	2	3	—	11
	13	Ankerite	$(CaMgFeMn)CO_3$	8	4	1	—	—	—	3
	14	Gypsum	$CaSO_4.2H_2O$	14	8	3	—	1	—	4
	15	Apatite	$Ca_3(PO_4)_2$	2	0	—	—	—	—	—
	16	Fluorite	CaF_2	14	6	2	—	—	—	4
		(Also nos. 80, 83, 87, 107, and 108.)								
Carbon	17	Graphite	C	5	1	—	—	—	—	1
		(Also nos. 11, 12, 13, 33, 34, 48, 56, 60 and 64.)								
Cobalt	18	Several minerals	Co compounds	5	4	—	—	—	—	4
Copper	19	Copper	Cu	4	3	1	—	—	—	2
	20	Chalcopyrite	$CuFeS_2$	179	81	2	32	—	—	47
	21	Bornite	Cu_3FeS_3	18	7	—	4	—	—	3
	22	Chalcocite	Cu_2S	14	8	1	1	1	2	3
	23	Covellite	CuS	4	2	—	1	—	—	1

TABLE VI.—*Continued.*

Minerals of	No.	Name.	Composition.	Total.	Ex-plicit.	Inter-grown.	Dissem-inated.	Upon.	In.	With.
Copper	24	Enargite	Cu_3AsS_4	6	2	—	—	—	—	2
	25	Famatinite	$Cu_3(SbAs)S_4$	1	1	1	—	—	—	—
	26	Tennantite	$Cu_8As_2S_7$	5	3	—	1	—	—	2
	27	Tetrahedrite	$Cu_8Sb_2S_7$	55	30	3	10	—	—	17
	28	Bournonite	$(Cu_2Pb)_3Sb_2S_6$	4	0	—	—	—	—	—
	29	Aikinite	$(Cu_2Pb)_3Bi_2S_6$	3	3	2	—	—	1	—
	30	Goldfieldite	$5CuS(SbBiAs)_2(SeTe)_3$	1	1	1	—	—	—	—
	31	Cuprite	Cu_2O	2	1	—	—	—	—	1
	32	Melaconite	CuO	3	2	—	—	1	—	1
	33	Azurite	$2CuCO_3.Cu(OH)_2$	9	4	1	1	—	—	2
	34	Malachite	$CuCO_3.Cu(OH)_2$	19	6	—	2	—	—	4
	35	Chrysocolla (Also no. 98.)	$CuSiO_3.2H_2O$	11	4	—	—	—	2	2
Gold	36	Calaverite	$AuTe_2$	5	2	2	—	—	—	—
	37	Krennerite	$AuTe_2$	3	2	1	—	—	—	1
	38	Sylvanite	$AuAgTe_4$	8	1	1	—	—	—	—
	39	Unidentified tellurides (Also nos. 55 and 94.)	Au-Te compounds	4	3	—	—	—	—	3
Iron	40	Pyrite	FeS_2	337	171	8	112	8	3	40
	41	Marcasite	FeS_2	21	11	1	2	—	—	8
	42	Pyrrhotite	Fe_nS_{n+1}	37	19	2	6	—	—	11
	43	Löllingite	$FeAs_2$	5	3	—	3	—	—	—
	44	Arsenopyrite	$FeAsS$	104	53	1	30	3	0	19
	45	Hematite	Fe_2O_3	19	11	—	2	1	—	8
	46	Limonite	$2Fe_2O_3.3H_2O$	28	14	2	3	1	2	6
	47	Magnetite	Fe_3O_4	24	7	1	1	—	1	4
	48	Siderite	$FeCO_3$	22	9	—	2	—	—	7
	49	Emmonsite	Ferric tellurite	2	0	—	—	—	—	—
	50	Scorodite (Also, nos. 13, 20, 21, 63, 79, 80 and 83.)	$FeAsO_4.2H_2O$	3	0	—	—	—	—	—

TABLE VI.—*Continued.*

TABLE VI.—*Continued.*

Minerals of	No.	Name.	Composition.	Total.	Explicit.	Intergrown.	Disseminated.	Upon.	In.	With.
Lead	51	Galenite	PbS	221	98	11	41	1	1	44
	52	Clausthalite	PbSe	1	1	—	1	—	—	—
	53	Altaite	PbTe	6	3	2	—	—	—	1
	54	Jamesonite	$Pb_2Sb_2S_5$	5	4	—	2	—	—	2
	55	Nagyagite	$Au_2Pb_{10}Sb_2Te_6S_{15}$	9	4	—	1	1	—	2
	56	Cerussite	$PbCO_3$	8	4	—	1	—	—	3
	57	Anglesite	$PbSO_4$	2	1	—	1	—	—	—
	58	Pyromorphite	$(PbCl)Pb_4(PO_4)_3$	1	1	—	1	—	—	—
	59	Crocoite (Also nos. 28, 29, 68 and 110.)	$PbCrO_4$	3	0	—	—	—	—	—
Magnesium	60	Magnesite (Also nos. 12, 13, 80, 82, 84 and 85.)	$MgCO_3$	3	3	1	1	—	—	1
Manganese	61	Alabandite	MnS	4	2	—	—	—	—	2
	62	Several minerals	Mn oxide	13	5	—	2	—	—	3
	63	Franklinite	$(FeMn)_2(FeMnZn)O_4$	1	1	—	1	—	—	—
	64	Rhodochrosite	$MnCO_3$	16	8	—	—	—	1	7
	65	Rhodonite (Also no. 13.)	$MnSiO_3$	4	2	—	—	—	1	1
Mercury	66	Cinnabar	HgS	7	2	—	—	—	—	2
Molybdenum	67	Molybdenite	MoS_2	12	4	1	—	—	—	3
	68	Wulfenite	$PbMoO_4$	4	0	—	—	—	—	—
Nickel	69	Annabergite	$Ni_3(AsO_4)_28H_2O$	1	1	—	—	1	—	—
Palladium	70	Allopalladium	Pd	1	1	1	—	—	—	—
Potassium	71	Alunite (Also nos. 76, 78 and 79.)	$K(AlO)3(SO_4)_23H_2O$	2	2	—	—	—	—	—
Selenium	72	Unidentified Se compounds (Also nos. 30 and 52.)		5	1	1	—	—	—	0
Silica	73	Quartz	SiO_2	(Always present, though sometimes insignificant.)						
	74	Chalcedony	SiO_2	15	8	3	—	—	—	5
	75	Opal	$SiO_2.nH_2O$	6	4	3	—	—	—	1
	76	Orthoclase	$KAlSi_3O_8$	15	7	—	—	—	—	7

TABLE VI.—*Continued.*

Minerals of	No.	Name.	Composition.	Total.	Explicit.	Intergrown.	Disseminated.	Upon.	In.	With.
	77	Albite	$NaAlSi_3O_8$	10	5	1	—	—	—	4
	78	Muscovite	$(SiO_4)_3Al_3(KNa)\ H_2$	24	10	—	—	—	—	10
	79	Biotite	$(SiO_4)_23(AlFe)_2(MgFe)_2(KH)_2$	4	3	—	—	—	—	3
	80	Hornblende	$(MgFe)_3CaSiO_{12}$	5	3	1	—	—	—	2
	81	Pyroxene	variable.	4	2	1	—	—	—	1
	82	Chlorite	hydrous Mg-Al silicate	18	7	1	—	—	—	6
	83	Epidote	$H_2Ca_4(AlFe)_8Si_6O_{25}$	12	5	—	—	—	—	5
	84	Serpentine	$H_4Mg_3Si_2O_9$	4	2	—	—	2	—	—
	85	Talc	$H_2Mg_3Si_4O_{12}$	2	1	—	—	—	—	1
	86	Kaolinite	$H_4Al_2Si_2O_9$	19	14	—	—	1	3	10
	87	Wollastonite	$CaSiO_3$	3	3	—	—	—	—	3
	88	Garnet	variable	13	8	—	1	—	—	7
	89	Tourmaline	complex	16	8	3	—	—	—	5
	90	Zircon (Also nos. 35, 65, 106 and 110.)	$ZrSiO_4$	2	2	—	1	—	—	1
Silver	91	Silver	Ag	32	17	1	—	—	—	16
	92	Argentine	Ag_2S	39	14	1	5	—	1	7
	93	Hessite	Ag_2Te	5	3	3	—	—	—	—
	94	Petzite	$(AgAu)_2Te$	9	4	2	—	—	—	2
	95	Pyrargyrite	Ag_3SbS_3	17	4	—	—	—	—	4
	96	Stephanite	$Ag_{10}Sb_2S_8$	8	1	—	1	—	—	—
	97	Miargyrite	$AgSbS_2$	2	0	—	—	—	—	—
	98	Polybasite	$(AgCu)_8SbS_6$	5	1	—	—	—	—	1
	99	Proustite	$Ag_3As\ S_3$	7	3	1	—	—	—	2
	100	Cerargyrite (Also no. 38.)	AgCl	7	1	—	—	—	—	1
Sodium		(Nos. 77 and 78.)								
Sulphur	101	Sulphur (Also numerous minerals in this table.)	S	2	0	—	—	—	—	—

TABLE VI.—*Continued.*

Minerals of	No.	Name.	Composition.	Total.	Explicit.	Intergrown.	Disseminated.	Upon.	In.	With.
Tellurium	102	Tellurium	Te	1	1	1	—	—	—	—
	103	Tellurite	TeO_2	3	3	—	—	—	—	3
	104	Unidentified Te compounds (Also nos. 9, 30, 36, 37, 38, 39, 49, 53, 55, 94.)		8	1	—	—	—	—	1
Tin	105	Cassiterite	SnO_2	3	0	—	—	—	—	—
Titanium	106	Rutile	TiO_2	6	2	—	—	—	—	2
	107	Titanite	$CaSiTiO_5$	3	3	—	—	—	—	3
Tungsten	108	Scheelite	$CaWO_4$	9	2	1	—	—	—	1
Uranium	109	Uranium ocher	U oxide	1	1	1	—	—	—	—
Vanadium	110	Roscoelite	V mica	6	5	5	—	—	—	—
	111	Vanadinite	$(PbCl)Pb_4(VO_4)_3$	2	0	—	—	—	—	—
Zinc	112	Sphalerite (Also no. 63.)	ZnS	163	69	7	18	5	—	37

number of cases in the "Intergrown" and "Disseminated" columns of the table and dividing the sum by the amount in the "Explicit" column. Omitting those minerals for which the sum of the two columns is less than 2, the tendency for gold to precipitate with metallic minerals is in the following decreasing order:—löllingite, bismuth, tetradymite, calaverite, hessite, bismuthinite, pyrite, aikinite, altaite, arsenopyrite, galenite, petzite, jamesonite, pyrrhotite, tetrahedrite, argentite, chalcopyrite, stibnite, and sphalerite. For non-metallic minerals it is: roscoelite, quartz, opal, magnesite, chalcedony, tourmaline, barite and calcite.

Examining the "Upon" column in a similar manner, it is found that the tendency to be precipitated upon minerals is in the order dolomite, barite, sphalerite, calcite, arsenopyrite and pyrite. The relative tendency of gold to occur in minerals which have been precipitated upon it is not brought out by the figures in the table.

In nine minerals more than 25 per cent. of the explicit instances contain disseminated gold. These are all metallic minerals and stated in the order of decreasing percentages are löllingite, pyrite, arsenopyrite, galenite, chalcopyrite, argentite, tetrahedrite, pyrrhotite, and sphalerite. When we consider intergrown cases we find that only four with a percentage above 25 are metallic minerals—hessite, aikinite, and bismuthinite and petzite; while seven are non-metallic—roscoelite, quartz, opal, chalcedony, tourmaline, gypsum, and barite. It will be observed that the presence of the common sulphides and of minerals of arsenic and antimony appears to be favorable to the precipitation of disseminated gold; while the presence of non-metallic minerals and of minerals of bismuth and tellurium appears to be favorable to the precipitation of native gold in visible particles.

Since finely disseminated gold occurs most commonly in association with opaque ore minerals, its character may best be investigated by the microscopic examination of polished surfaces. The first question that naturally arises is: How much gold must there be in an ore to enable one to detect it on a polished surface?

In the course of the ordinary microscopic examination of a polished surface, the smallest particle of gold likely to be observed would be one 0.01 mm. in diameter. The average polished specimen has about the dimensions of a 20-mm. cube. In order that any section parallel to the face of such a cube shall show a section of gold 0.01 mm. in diameter, the cube must contain 3 rods of gold 20 mm. long and 0.01 mm. in diameter arranged at right angles to one another and parallel to edges of the cube, or their equivalent. This is the smallest amount possible and it would weigh 0.1 mg. If the specific gravity of the cube of ore as a whole were 5, which is a fair average figure, 0.1 mg. of gold in such a cube would mean a content of $1.50 per ton of ore. Under the most favorable conditions, then, we might hope to find a speck of gold in a polished surface of ore assaying $1.50 per ton.

If the gold were present in particles one tenth this diameter, it could not be identified, and if in particles one hundredth this diameter it could not be seen under the most powerful microscope, so that a very high content of finely divided native gold might be entirely invisible just as it was in the case of the ruby glass which assayed $60 per ton. On the other hand, if the same quantity of gold were present in larger particles, the chances of finding one of these particles on a polished surface would be greatly reduced.

By way of illustration, let us consider the case of ore from the Homestake mine, South Dakota. This averages about $3 per ton, and so under the most favorable conditions might show two specks of gold on each polished surface. The writer examined a dozen polished specimens of ores from various parts of this mine without finding a single flake of gold. This may mean that the gold was present in a finely divided state, indeed it is altogether probable that much of the Homestake gold exists in such a condition, but another explanation is possible. In Fig. 32 there are shown three native gold specimens from the Homestake mine.[1] The smallest particle of native gold among these, the

[1] These specimens were obtained through the kindness of Mr. P. E. Peterson, a student in the Montana State School of Mines.

crystal in milky quartz, weighs about 150 mg. This one specimen therefore contains enough gold to bring up to $3 grade 750 specimens entirely devoid of gold!

The microscopic gold in an ore may be older than the adjacent minerals, contemporaneous with them, or have been formed at some later period. Sharply crystallized native gold attached to one side of a microscopic fissure in milky quartz which at a later date had been filled by chalcocite surrounding the gold except at

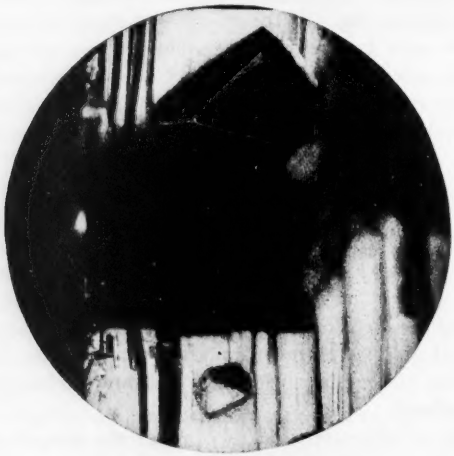


FIG. 33. Gold and Galenite Crystals in Pyrite. The greater part of the field is taken up by two crystals of pyrite. In the left hand one is embedded a gold crystal and in the right hand a galenite crystal.

its point of attachment has been described and figured from the Promontorio mine, Durango, Mexico, by the writer.[1]

The principal interest centers about contemporaneous intergrowths of gold with other minerals. Figures 33 and 34 show such an association of native gold with pyrite and galenite. The gold projects beyond the pyrite and the galenite as little sharp

[1] *Trans. Amer. Inst. Min. Eng., 38,* 1907, 745.

crystals. In Fig. 33, a gold crystal and a galenite crystal are to be seen projecting from adjacent pyrite crystals; while Fig. 34 shows several gold crystals projecting from a galenite crystal. In one of the specimens from the Homestake mine illustrated in Fig. 32, arborescent gold occurs intergrown with magnesite, quartz and chlorite, the three latter minerals being so closely associated as to be indistinguishable save in thin section. Magnesite also occurs

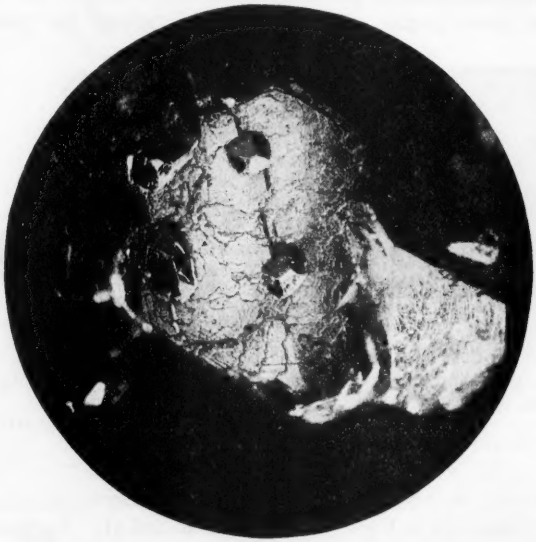


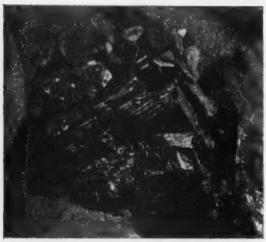
FIG. 34. Gold Crystals in Galenite. Same specimen as Fig. 1. Enlarged 7 diameters.

in gold veins in the Idaho Springs district, Colorado,[1] and in northern and eastern Transvaal.[2] The veins of both of these districts as well as those of the Homestake are in Archean schists. Fig. 35 is a microscopic enlargement of a very rare association

[1] Spurr and Garrey, U. S. G. S. Bull., *285*, 1906, 35.
[2] C. Hintze, "Handbuch der Mineralogie," *1*, 1904, 306.

from the Fairview mine, near Ophir, Mont.[1] Near the center of the field, arborescent native gold may be seen intergrown with a crystal of proustite, while three other less well-marked intergrowths occur elsewhere in the photograph.

When contemporaneous intergrowths of native gold with metallic minerals are examined in section, curved outlines are found to be very common. Microscopic intergrowths examined on polished surfaces are characteristically rounded with occasional sharp angles. This peculiarity is shown for galenite,



35 36 37

FIG. 35. Gold Ore from Amador County, California.

FIG. 36. Gold (black) Contemporaneous with Galenite. Montgomery County, Md.

FIG. 37. Gold (black) Contemporaneous with Pyrrhotite and Quartz (*Q*). Great Fingall Mine, West Australia.

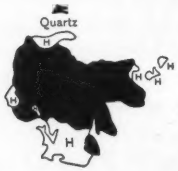
pyrrhotite, tetradymite, hessite or petzite, calaverite or sylvanite and tetrahedrite in Figs. 36, 37, 38, 39, 40 and 41. So typical is this structure, that it is believed the gold in tetrahedrite from Promontorio, Mexico, which was originally described as younger than the tetrahedrite is in reality contemporaneous, since its outlines have the same alternations of curves and sharp angles exhibited in the figures referred to above.

Rich ore from the Mohawk mine, Goldfield, Nev., is illustrated by Figs. 40, 41 and 42. The ore is quartz containing ribbons of sylvanite or calaverite. Intergrown with the telluride is a smaller

[1] This specimen was presented to the writer by Mr. J. Rowand, of Helena.

amount of tetrahedrite, probably the antimonial variety, famatinite, since that is common at Goldfield. Pyrite crystals are also present in the quartz, but they are usually segregated in portions of the ribbons and only rarely come in contact with the telluride and tetrahedrite. One of these rare instances is illustrated in

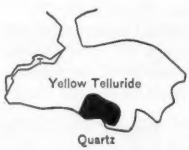
38



39

FIG. 38. Gold (black) Contemporaneous with Tetradynite and Quartz. Cable mine, Montana.

FIG. 39. Gold (black) Contemporaneous with Hessite or Petzite (*H*) and quartz. Boulder Co., Colo.



40

41

42

FIG. 40. Gold (black) Contemporaneous with pale yellow Telluride, Tetrahedrite (*T*) and Quartz and most intimately Associated with the Telluride. Mohawk mine, Goldfield, Nevada.

FIG. 41. Gold (black) Contemporaneous with Tetrahedrite (*T*) pale yellow telluride (*Y*) and Quartz, and most intimately Associated with the Tetrahedrite. Mohawk mine, Goldfield, Nev.

FIG. 42. Ore from Mohawk mine, Goldfield, Nevada, showing Contemporaneous Deposition of Gold (black) pale yellow Telluride (*Y*), Tetrahedrite (*T*), Pyrite (*P*) and Quartz.

Fig. 40. To a still smaller extent, native gold is present. The gold is undoubtedly primary as can be seen by inspection of the three figures. It is commonly intergrown with the tetrahedrite, and more rarely with the yellow telluride.

Sharwood[1] described the occurrence of irregular particles of native gold and a pale yellow telluride resembling sylvanite, the two minerals being sometimes separate and sometimes mixed, in a silicified porphyry from Goldfield. Ransome[2] held that gold tellurides had not been satisfactorily identified from Goldfield;

43 44 45

Fig. 43. Ore from El Oro mine, Mexico, showing Contemporaneous Deposition of Gold (black) Galenite (*G*), Chalcopyrite (*C*), Pyrite, Quartz and Sphalerite.

Fig. 44. Ore from Kalgoorli, Western Australia, showing Contemporaneous Deposition of Gold (black) Hessite or Petzite (*H*), Pyrite (*P*) and Quartz.

Fig. 45. Replacement by Gold and Galenite. Bald Butte mine, Montana.

and suggested that Sharwood's "sylvanite" might really be marcasite. The pale yellow telluride found by the writer has the structure and reactions with acids which are typical of sylvanite and calaverite, and could not possibly be marcasite.

The ores of Goldfield are thus seen to have several marked points of resemblance to those of Cripple Creek. The unoxidized telluride ores of the latter camp have a part, though a very

[1] *Min. and Sci. Press, 94,* 1907, 73.

[2] U. S. Geol. Sur. Prof. Paper, *66,* 1909, 116.

small part, of their gold free; primary gold has been found in tetrahedrite; and calaverite and tetrahedrite are frequently found intergrown.[1]

In Fig. 43, the microscopic character of rich ore from the El Oro mine in Mexico is shown. The specimens studied showed no gold visible to the naked eye, indeed it is said that colors can seldom be detected at the mine.[2] Polished surfaces examined under the microscope showed the presence of gold in minute specks. The gold was pale yellow in color indicating a considerable silver content. From the figure it can be seen that while the gold appears to be contemporaneous with quartz, pyrite, galenite, sphalerite and chalcopyrite, it is most intimately associated with the galenite. This association has not apparently been recognized before, the only statement found concerning the direct association of the gold being that it occurs associated with argentite on the lower levels of the mine.[3]

Most of the native gold found at Kalgoorli, West Australia, is "mustard" gold, formed by the oxidation of gold tellurides. Such gold has been described and figured by Sharwood.[4] Primary gold of contemporaneous age with a white telluride (petzite or hessite), pyrite, and quartz is illustrated in Fig. 44. This occurrence is similar to that of Boulder County, Col., shown in Fig. 39.

Replacement on a microscopic scale is illustrated by Fig. 45 representing rich ore from the Bald Butte mine in Marysville district, Mont.[5] This ore originally consisted of quartz, pyrite and an unknown radiating lamellar mineral now completely replaced by gold and galenite. Chalcopyrite and sphalerite are also present but do not enter into direct association with the gold in so far as observed. Microscopic rods of gold occur in the galenite in positions uninfluenced by the earlier formed quartz and pyrite. The unusual form of the gold shows that its deposition was affected by the shape of the mineral which it replaced.

[1] Lindgren and Ransome, U. S. Geol. Sur. Prof. Paper, *54*, 1906, 115 and 169.
[2] Caetani and Burt, *Trans. Amer. Inst. Min. Eng.*, *37*, 1906, 3.
[3] T. A. Rickard, *Min. and Sci. Press*, 1906, 352.
[4] *Min. and Sci. Press*, *94*, 1903, 731.
[5] Obtained through the kindness of Mr. W. G. Brown, of Helena.

Fig. 46 illustrates fissure filling on a microscopic scale in rich ore from the Crœsus mine, Cal. Arsenopyrite has been shattered and quartz, galenite and gold deposited in the fissures. The irregular outlines of the arsenopyrite and the enlargements associated with fissures indicate that replacement of the arsenopyrite by the later minerals occurred.

Fig. 46. Gold filling microscopic Fissures in Arsenopyrite (*A*) and Contemporaneous with Quartz (*Q*) and Galenite (*G*). Crœsus mine, Calif.

The writer examined a large number of polished specimens from other mines, occasionally finding gold but more commonly failing to do so. None of the other cases in which gold was found present points of special interest. It should be noted as peculiar, and perhaps significant, that no instances of gold in direct microscopic association with chalcopyrite were observed, although numerous specimens containing that mineral were examined. This suggests that the gold in chalcopyrite may exist

in an extremely finely divided state more frequently than it does in most of the other sulphides. Greater weight is added to this view when it is noted that only two recorded instances of gold macroscopically intergrown with chalcopyrite are listed in Table V. Even in these two instances the evidence for intergrowth is incomplete. The gold from Schlangenberg in the Altai Mountains is said to occur native mostly intergrown with barite but also with stromeyerite, argentite, and a mixture of chalcopyrite and galenite:[1] while the gold from the Clogau mine in Wales is said to occur mostly disseminated in quartz but also intergrown with pyrite, chalcopyrite, tetradymite and galenite.[2] It is quite possible that a careful examination of gold specimens from these localities might show that the gold occurred adjoining rather than intergrown with the chalcopyrite. Arsenopyrite is another mineral which according to the table might be expected to usually contain its gold in a very fine state of division. The number of arsenopyrite specimens examined by the writer was too small to permit of any positive generalization, although no intergrown gold was observed in any case.

V. CONCLUSIONS.

In igneous and metamorphic rocks native gold has been found and studied in only a few instances. In these cases the gold occurs throughout the various minerals of the rocks, but in the metamorphic rocks it shows a tendency to associate most intimately with the magnetite. In sedimentary rocks native gold has been frequently observed in association with the heavier and less soluble constituents of the rocks. It is probable that the small amounts of gold found by chemical analyses of typical igneous, sedimentary and metamorphic rocks exist in these rocks as native gold in grains similar to those in the observed cases but more widely distributed or of smaller size.

The gold in veins occurs associated with upwards of 173 mineral species, but of these there are only a few which when

[1] C. Hintze, "Handbuch der Mineralogie," *1*, 1904, 272.
[2] J. M. Maclaren, "Gold," 1908, 129.

present with the gold are more apt to contain intergrown and disseminated gold than not. These minerals are quartz, opal, roscoelite, magnesite, pyrite, galenite, hessite, altaite, calaverite, tetradymite, selenium minerals, löllingite, arsenopyrite, bismuthinite, aikinite and bismuth. If we except the non-metallic minerals and the two common sulphides, pyrite and galenite, it will be seen that these minerals all contain either arsenic, bismuth, selenium or tellurium, substances which are closely associated with one another in the periodic system of the elements but are widely removed from gold.[1]

Microscopic gold particles occur enclosed in later minerals, intergrown with contemporaneous minerals, and upon younger minerals. Microscopic gold may fill fissures or replace other minerals. Thus all the varieties of paragenesis which have been observed on a macroscopic scale also exist on a microscopic scale. It seems highly probable that the same relations existing between gold and other minerals on macroscopic and microscopic scales also exist on a sub-microscopic scale. Such a hypothesis accounts satisfactorily for the peculiarities of many ores in which native gold is seldom or never seen and in which no gold telluride nor other gold mineral has been identified.

In conclusion, the writer wishes to express his thanks to Professor Kemp and Professor Berkey, of Columbia University, for their kind and valuable advice and to Messrs. Ricketts and Banks, mining and metallurgical engineers of New York City for the use of their laboratories. He also ventures to express the hope that the United States Geological Survey or some other institution of high standing may take up the determination of the gold content of rocks on a more extended scale than has hitherto been attempted. Mining geologists are paying more and more attention to the exact manner in which the gold is present in gold ores, and generalizations of greater weight than those contained in the present paper will undoubtedly be possible in the course of a few years.

[1] For a recent statement of associations of gold with tellurium and with bismuth and tellurium see W. J. Sharwood, this magazine, *6*, 1911, 29.

THE ORIGIN OF THE RAMMELSBERG ORE DEPOSIT.

WALDEMAR LINDGREN AND JOHN DUER IRVING.

INTRODUCTION.

In the course of a brief visit to the great copper deposit of Rammelsberg on the northern slopes of the Harz Mountains the authors had an opportunity to study the occurrence and mineralogy of its ores. The results of such a short investigation are, of course, entirely insufficient as a base for a detailed description. Nevertheless, it appeared to them as if certain relations not previously emphasized might help to elucidate the difficult and much discussed question of the genesis of that ore deposit. For kind permission to visit the mine the writers are indebted to Oberberghauptman Krümmer in Clausthal and to Bergrath Wolff, of Goslar. For our guidance in the mine we are under obligations to Obersteiger Voigt, who directs the exploitation of the deposit.

The Rammelsberg deposit, as shown on the accompanying map, Fig. 47, is situated on the northern slope of the Harz Mountains in close vicinity to the town of Goslar. As well known, it has been worked for copper ores since ancient times, the first records dating back to the tenth century. Its geological structure has been investigated by a number of authors, but its complete and detailed description is as yet a problem of the future. The most diverse explanations have been offered as to its mode of origin. By some, perhaps by a majority, including such well-known geologists as Bergeat and Klockmann, it has been considered as a sedimentary deposit contemporaneous with the surrounding sedimentary rocks. Others, like Professor Vogt, following Freiesleben and Lossen, explain it as a deposit from solutions immediately derived from igneous magmas. Still others, like Professor Beck, occupy a non-committal standpoint.

Geology and Structural Features.—The deposit is enclosed, apparently conformably, in Devonian rocks, which at Goslar appear as an overturned anticlinal and dip towards the north. It lies in the so-called Goslar slates of the Middle Devonian; these slates being again overlain by a thick series of Lower Devonian Spirifer sandstone, which makes up the summit of the Rammelsberg Mountain, at the foot of which the mine is located. The following cut (Fig. 48) after Klockmann will show these relations.

The slates have suffered considerable contortion and the ore

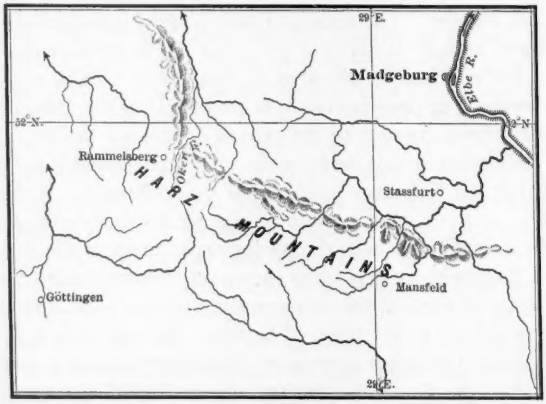


FIG. 47. Sketch map showing location of Rammelsberg.

body apparently follows these contortions more or less clearly. The underground developments extend over a horizontal distance of about 2,000 meters and have attained a vertical depth from the surface of 380 meters from the level of the Richtschacht. It will be seen from this that mining has not yet penetrated to great depths in spite of the fact that the deposit has been worked for nearly a thousand years. The ore body is divided horizontally into two parts; respectively referred to as the old and the new

beds; they are connected by a narrow and contorted seam showing, however, beyond doubt that the two are really parts of one deposit.

The following sketch, after Klockmann shows the relation of these two ore-masses as seen in plan.

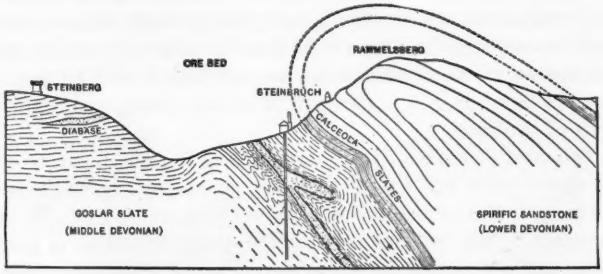


FIG. 48. Cross-section of Rammelsberg ore deposit showing overturned anticline and manner in which the deposit is believed by earlier writers to be conformable to the lamination of the enclosing slates. (After Klockmann.[1])

The thickness of the ore bed, as it is generally referred to, varies considerably; in places it swells to dimensions of as much as 30 meters, but this is rather due to folding and local enlargement. In most places where we observed it in the workings the thickness did not extend over 2 or 3 meters and was sometimes

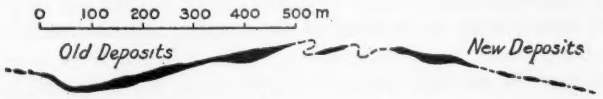


FIG. 49. Plan of the Rammelsberg ore body showing the relation of the old and new ore body. (After Klockmann.)

only 0.5 to 1 meter. The dip is vertical uniformly 45° to the southeast. In depth the ore in general appears to become a little richer in zinc and barite. At present the ores are sorted by hand at the surface and transported by wagons to the railroad, about

one mile distant. The older methods of working are now being replaced by more modern ways of exploitation. One of the main difficulties in the treatment of the ore lies in the fine grained intergrowth of chalcopyrite, zinc-blende and galena, which is eminently characteristic of the deposit.

It is stated, even in the modern descriptions of the Rammelsberg, such as that of Professor Beck,[1] in the third edition of his book on ore deposits, that the bedding or schistosity absolutely conforms with the outline of the ore and with its banded structure. The ore is said to take part in all the folding and contortions of the slate.

This idea of a mass of ore conformable to the schistosity of the slates, which has for so long been accepted in regard to this ore body, is shown in the well-known cross-section (Fig. 48) of the older of the two ore lenses. The slaty lamination is here shown curving around the irregular offshoot or apophysis which is figured in this section.

In view of the widely circulated opinion of this conformity the writers were surprised to find that, while true in places, it is certainly not a general characteristic of the deposit. In part, as was first noted, and called to their attention by Bergrath Wolff, it is absolutely unconformable to the stratification of the slate.

The ore *banding* follows in all cases with great faithfulness the outlines of the sulphide mass whether these be long smooth borders or small detailed irregularities of outline. For much of the distance above the third level the *edge* of the new ore body, and consequently the banding of the ore also, is indeed parallel to the lamination of the enclosing rock. On the third level, however, the ore mass flattens out and crosses the lamination at an angle of only a few degree, to again turn down parallel to it after intersecting the laminae for a very considerable distance. In this portion of the mass the banding of the ore follows the edge of the sulphide mass and makes therefore the same angle with the lamination of the slates as the outline of the ore mass itself.

[1] Beck, "Lehre von den Erzlagerstätten," 3d ed., Vol. 2, pp. 134–138.

The relations are shown in the sketches I and II of Fig. 50 below:

Where the ore crosses the lamination of the slates it is about five feet in width and shows no differences in either material or structure from that portion which is parallel to the structure of the enclosing rock. The outline of this ore body is not a plane but a warped surface which shows broad gentle undulations of large radius. Occasionally a sharp inequality is present and the ore veers off in a projection or apophysis only a few inches in

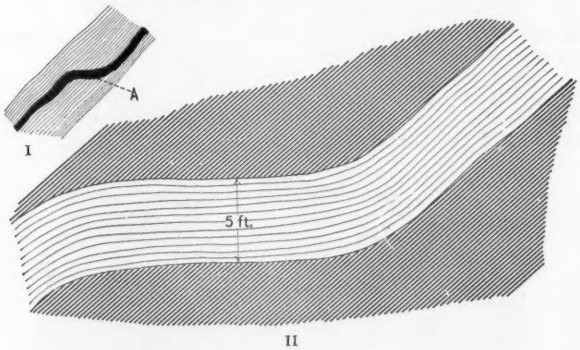


FIG. 50. Sketch of new ore body, 3d level, Rammelsberg. I shows manner in which the ore body, which is conformable with the lamination of the enclosing slates crosses this lamination at the point *A*. II is an enlarged sketch of the transition zone *A* showing how the banding of the ore truncates the lamination of the schists and how this lamination terminates abruptly at the ore and continues in the same direction on the other side.

cross section for a distance of 8 to 10 inches into the slate. One of these is shown in Fig. 51.

In this case the gneissoid banding of the ore still follows the outline of the periphery and runs into the apophysis with a series of embayment shaped lines, which exactly parallel in their arrangement the lines drawn on a map to indicate bodies of water which follow faithfully the outline of the shore absolutely irrespective of the structure or nature of the material of which the land may be composed.

In another place on the third level the new bed is folded into the form of an *S* as shown in Fig. 52. Here also the gneissoid

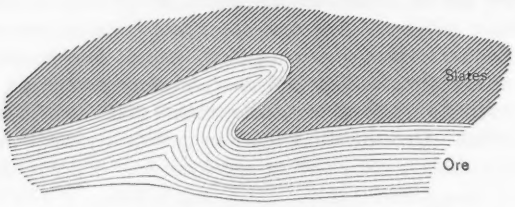


FIG. 51. Small embayments about eight inches wide, showing how banding of ore follows smaller inequalities in the enclosing rock.

banding follows with perfect faithfulness the periphery of the mass while the schistosity is abruptly truncated by it.

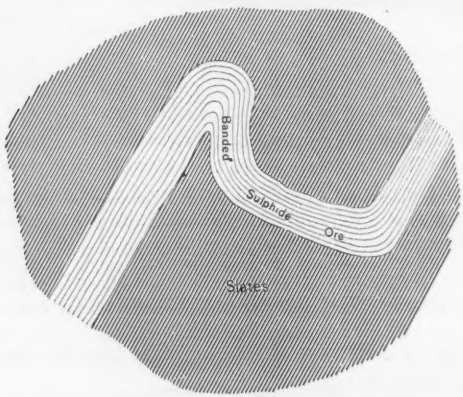


FIG. 52. Sketch of S-shaped fold in new ore body, 3d level, Rammelsberg mine. Shows how banding of ore truncates the lamination of the enclosing rock.

In all cases where the ore bodies are set at an angle to the bedding the laminae of the slates extend up to and terminate abruptly against the sulphide mass and thus continue in the same

direction on the opposite side. They do not enter it nor are they in the least distorted against it.

The Ores.—A number of varieties of ores are recognized. The principal minerals are zinc-blende, chalcopyrite, galena, pyrite and arsenopyrite; the quantity is approximately proportional to the place of the minerals as enumerated. The gangue is almost entirely barite, but rarely appears in large quantities,

FIG. 53. Lenticular augen, Rammelsberg Ore. Shows also fine banding and intimate intergrowth of minerals.

and often is entirely inconspicuous. Masses and veinlets of calcite are often found in the surrounding slate, but rarely contain ore. On the whole the limits of the "ore bed" are sharply defined and the ores themselves are entirely or predominantly composed of sulphides. An alteration of the enclosing slates is rarely observed. At most there is a slight im-

pregnation of pyrite. The so-called *kupferkniest,* which adjoins the ore in certain places, is a siliceous argillite which contains disseminated pyrite and chalcopyrite. It has often been con-

FIG. 54. Lenticular augen of pyrite in Rammelsberg Ore. *A A A A A* = Pyrite lenses, *B* = —.

sidered as an impregnation, later than the ore itself, but, as far as we could observe, there is no sufficient basis for such an interpretation.

The structure of the ore varies with the locality, and the composition also varies distinctly so that in one place the "ore bed" will contain predominant copper values, while in other places there is scarcely any copper, but only zinc-blende with a little galena.

The intergrowths of these minerals are very fine-grained and extremely intimate. By far the most common structure is that of

FIG. 55. A large nodule of barite and sphalerite in Rammelsberg Ore, showing banding of the ore and gneissoid structure.

the so-called Melir-Erze, which are intimately banded, in most cases consisting of dominant zinc-blende with narrow and gently curved streaks of chalcopyrite and galena. The appearance of the ore is reproduced in Figures 53 and 54. In places the ore contains rounded nodules, generally of pyrite, around which the fine-grained streaks of zinc-blende and chalcopyrite bend in regular curves. This is shown in Fig. 54, which also brings out the fact that the pyrite is in part drawn out into long streaks. In general, however, it shows a notable resistance to such deformation. Not uncommonly one finds rounded nodules consisting of

zinc-blende and barite in granular form, coarser than that of the ordinary ore. Fig. 55 illustrates an occurrence of this kind, which clearly shows how the streaks of other sulphides surround and envelop these nodules. The pyrite nodules have often been noted, but without satisfactory explanation. Some observers have held them for fossil remains, in which the pyrite has replaced the shell of the organism. A goniatite has actually been found in the slates forming the easterly continuation of the ore body, and, according to K. Andree,[1] the interior of the shell contained pyrite, quartz, barite and calcite.

Origin.—The structural relations of the ore body indicate, according to our view, without any doubt, that the deposit is a bedded vein; that is, a fissure vein lying in part conformable to the surrounding slates. The distribution and structure of the ore itself is inconsistent with the theory of sedimentary deposition. As far as our experience goes the structure is unique in ore deposits, but as to its interpretation there can be no reasonable doubt. The sulphides do not occur with their primary texture. The structure is that of a dynamo-metamorphic rock, in which all of the constituents, except pyrite, have been drawn out into streaks which are intricately mingled. The appearance shown in the figures could be easily duplicated from any fine-grained gneiss area resulting by pressure from an original granular rock. The different constituents have acted under pressure as plastic material and are thoroughly mashed and squeezed. It is difficult to avoid the conclusion that the sulphide mass has moved almost like a plastic clay and that the present structure is due to this movement. There is no evidence, in our opinion, to justify the assumption of sedimentary deposition.

At first glance it seems strange that the pyrite has acted so differently from the other constituents. The explanation of this behavior is easily found in some interesting experiments recently undertaken by Professor F. D. Adams.[2] In this memoir Pro-

[1] Andree, K., *Z. f. prakt. Geol.*, 1908, p. 166.

[2] Adams, F. D., "An Experimental Investigation into the Action of Differential Pressure on Certain Minerals and Rocks," *Jour. of Geol.*, 18, 1910, pp. 480–535.

fessor Adams shows that plasticity is a function of hardness, so that the minerals become less plastic as they become harder. He finds that the limit of easily produced plasticity lies in the vicinity of five or six in the scale of hardness. Pyrite in his experiments was crushed under a load attaining 43,000 pounds without showing any trace of plastic deformation. Minerals of lower hardness presented decided evidence of plastic flow. The pyrite nodules in the Rammelsberg ores are then simply residual parts of the original granular deposit which have been less deformed than the other sulphides.

In conclusion then, we regard the Rammelsberg deposit as one of epigenetic origin, in which the structure of the ore has been profoundly changed by dynamo-metamorphism. While the surrounding slates are soft they evidently behaved quite differently from the sulphide mass, which seems to have flowed almost like a thick mush between the slate walls. The reason for this difference in behavior is not as yet fully explained, but we believe the question could be settled experimentally by a method similar to that of Professor Adams.

The association of minerals with barite as predominating gangue tends to show, in our opinion, that the deposit is not of the deep seated type, but was formed at a medium depth below the original surface, probably, within a few thousand feet of it.

Regarding the source of the ores, the only suggestion we would like to offer is that the deposit may have been formed by ascending solutions derived from the neighboring batholith of granite, which is only three kilometers distant from the mine.

EDITORIAL[1]

SOME PROBABLE RESULTS FROM CONSERVATION.

Among subjects of general interest to the people of the United States, perhaps none is more frequently mentioned at the present moment than conservation of national resources. In the editorial by Professor J. F. Kemp which appeared in an earlier issue of this Journal much was said concerning the conservation policy —but the results of the present conservation policy have not been adequately stated. Although no two individuals agree as to the precise meaning and scope of conservation, yet because of the attitude of the public press and the general demand for something which bears this name we may take it for granted that the phrase appeals very strongly to the great mass of the people and especially to those who have no immediate connection with the mining industry. Sooner or later this interest is likely to find expression in the modification of the laws which for many years have governed the development and disposition of the public domain. Many bills have been already introduced into our state and national legislatures dealing with one or another of the various phases of the question. Few changes have been made as yet, but these are important, and it can hardly be doubted that the net result within a few years will be a radical reversal of the liberal provisions under which heretofore the natural resources of the country have been placed within the reach of the man whose enterprise, foresight and money were at command for their development. Already by congressional enactment and executive order those tracts of oil lands, water powers and forests still belonging to the public domain, have been either

[1] The signed editorials which it is designed to publish from time to time in these columns are expressions of individual views and do not represent the consensus of opinion of the editorial board.

entirely withdrawn from entry or placed upon a rental or royalty basis whose terms are at present a handicap to their operation and production. No longer does a homesteader receive in his patent a title to the surface of the ground as well as to all that lies beneath. No longer can the prospector hope to benefit by whatever he discovers. Even in far-away Alaska he can expect but meager reward. The valuable and attractive lands are either "temporarily" withdrawn from entry or are subject only to lease.

The general attitude in the older portions of the country and in the regions remote from the newer, sparsely settled and undeveloped territory, appears to be that conservation of this kind is an unalloyed blessing. Rarely if ever has a suggestion been made that it may eventually result to the disadvantage of the people at large. On the contrary, the wide-spread feeling is rather that of heirs who have at last attained their rights in an inheritance, long withheld by wicked and designing guardians. Few have considered that the profits accruing from the development of mineral resources are more often conditioned by wise, prudent and economical management than by the inherent value of the deposits themselves. To still fewer has it occurred that stagnation and paralysis may lie before, or that a horde of governmental officials is a poor exchange for the incentives and rewards which have hitherto crowned wisely directed individual effort. We may for a moment turn our attention to this phase.

The first result of a change in our national policies toward the development of resources will be—and indeed already in instances has been—a slackening of interest and a falling off in new enterprises. Greater and greater burdens are to be imposed upon capital. Costs will be increased and profits lessened, at least for a time. The man whose coal in the ground costs only a fraction of a cent per ton will have a marked advantage over the newcomer who must pay a high purchase price or royalty to the government. The same holds true with oil wells and water-powers. Indeed, a somewhat intimate familiarity with business conditions throughout the country from New York to Seattle and from Alaska to Arizona has forced upon me the

conviction that, as a result of the conservation movement, there is already a marked (and there will be a greater) decline in the number of new enterprises. The situation is deeply discouraging to the pioneer residents of large sections of the West; and we are already hearing loud protests against the eastern theory of conservation.

It is an economic truism that nations, like individuals, cannot long stand still. They must either progress or retrograde. When their own resources have been completely developed they must seek fields of endeavor elsewhere or soon begin to fall behind in the race for supremacy. Ultimately they will decay. In no field of human endeavor is there greater reward in individual and national growth than in successfully attacking and solving the problems of nature in new countries and under new conditions. Recognition of this fact has led to the establishment of technical schools and colleges which are liberally endowed and supported by private and public benefactions. From these institutions are coming each year a small army of graduate engineers, civil, electrical, mechanical and mining, ready and eager for employment in new fields of enterprise and development.

These men will be the first to realize the meaning and effect of conservation. Old and completed enterprises do not require new blood and energy. They are aleady in full operation under those whose labor and genius were devoted to their creation. It is in the new enterprises that the younger engineer who has gained the necessary experience, finds his opportunity to show his capacity, and to win a place in the profession. Any change in policy which restricts or destroys these opportunities will bear most heavily upon him. The demand for labor of all sorts will also be reduced, and Coxey's armies of the unemployed will again be possible. The resultant effect upon general business requires no description and need not concern us here. But the effect upon the attendance at our engineering schools and universities is something that may well engage the attention of our educators and even of our legislators and political economists.

Now, lest I be called an alarmist and an agitator, let me outline,

what in my opinion, are likely to be some of the further results of conservation in the United States.

Although timid and selfish, capital will not remain indefinitely cooped up and idle. It may even become courageous and look for other worlds to conquer. And in these days of rapid transit and cheap transportation, other worlds are not so remote as formerly, indeed, they have been. Mexico and Canada are already in close commercial relations with us and have been receiving for years past those contributions in the way of investments which have greatly aided their growth. South America and Siberia are not far away. Both are full of opportunities and will more and more attract the surplus which in our country will be seeking employment. Africa too is a land of great promise. Of the three, however, South America is the one to which our investors will most naturally turn and in that direction will flow American dollars and energy, American brawn and brain in the next two decades. There, ready to be had for the asking, are still lands, mines, forests and water-powers. There are farms and ranches and town-sites to be developed and populated and the people of those southern countries are waiting for our assistance. Argentine Republic has shown the possibilities, but as is well known, it has been chiefly assisted in its development by Europeans. Now, however, that the United States have gone so far and are apparently bent on going so much farther in establishing European conditions here—conditions in which a bureaucracy is so strong and a citizenry so weak—one must expect the money and the enterprising spirits to be increasingly attracted to the southern hemisphere.

The young student of engineering and the young geologist who are alive to the rapidly developing changes in American conditions will do well to inform himself about lands and peoples in which or among which the door of opportunity is still open or at least as with us has not begun to close.

REVIEWS

Report on the Tungsten Ores of Canada. By F. L. WALKER. Canada Department of Mines, Mines Branch, No. 25, Ottawa, 1909. Pp. 52, and 10 plates.

Dr. Walker leads up to his subject by reviewing the history, mineralogy and uses of tungsten, and quoting descriptions of a number of the tungsten deposits of the United States, with the milling methods used at those localities.

The principal tungsten deposits of Canada are those at Moose River, Halifax County, Nova Scotia, where scheelite occurs with much arsenopyrite and black tourmaline needles in quartz veins. The scheelite is very pure and is in sufficient quanity to be commercially valuable. In the same general region scheelite has been found as float, and in several gold mines. It has also been found near Windsor Junction, in the same county but forty miles distant, in deposits similar to those at Moose River.

Scheelite, wolframite and hübnerite have been found at numerous places in Canada, generally in close proximity to, or in connection with, gold and silver ores. Scheelite pebbles are found in the Caribou and Klondike gold placers, as they are at Tinton in the Black Hills, at Nome and on the Koyukuk River in Alaska.

Mineralogically, the most notable fact in the report is the number of places from which tungstite is reported. At the Kootenay Belle mine, near Salmo, B. C., tungstite formed the greater part of the tungsten ore. Analyses show molybdenum to be present in a number of scheelites.

Only at Moose River is tungsten ore being mined commercially.

FRANK L. HESS.

Practical Mineralogy Simplified. By JESSE PERRY ROWE. Wiley & Sons, New York, 1911. Pp. 156 and two tables.

The wording of the title gives the reader a hint of the qualities to be expected in this book, which, as the sub-title further informs him, is intended for mining students, miners and prospectors. To present simply and effectively the elements of a science requires a special kind of skill, not only in choice of material and in neat, accurate and concise ex-

pression but also, particularly in the case of a subject where form plays so notable a part as in mineralogy, in the use of graphic illustration. To omit drawings and diagrams where they might have been so well used is to forego the most direct way of conveying ideas to minds accustomed to concrete thinking.

In the present work the simplification of the subject matter appears to consist chiefly in the complete avoidance of illustrations and chemical formulas and in the use of a homely style of description that sets rules of grammar at naught. The result cannot be commended.

F. L. RANSOME.

Elements of Geology. By ELIOT BLACKWELDER and HARLAN H. BARROWS. American Book Co., New York, 1911. 8vo, 475 pp.

This is a beginner's book in geology written by men whose experience well qualifies them for the task. It deals first with physical geology, taking up in order the composition of the earth, physical changes in the outer shell, the work of the atmosphere, the work of waters underground, the work of streams and glaciers, oceans and lakes, and the great relief features of the land. The various geologic processes are briefly and very clearly described and are illustrated by appropriate views and diagrams, most of which are excellent. Then follows a review of historical geology, the characterization of each period being very successfully done in view of the great mass of material that must be omitted from an elementary book. From the author's statement that *Carboniferous* as a period name had been abandoned in favor of *Mississippian, Pennsylvanian* and *Permian,* the reader might perhaps conclude that geologists were thoroughly agreed on this step. Such, however, can hardly be the case so long as the U. S. Geological Survey and geologists abroad treat these three divisions or their equivalents as parts of the Carboniferous system. Comanchean, once regarded as the lower division of the Cretaceous, is treated as a period between the Jurassic and Cretaceous proper, the authors in this respect, as in the divisions of the Paleozoic, following Chamberlin and Salisbury's great text-book.

The book is evidently intended for young students, and at the end of each chapter questions are provided of a kind to test and encourage the reasoning power rather than the memory. In its accuracy of statement, orderly arrangement of subject matter, simplicity and clarity of style and effectiveness of illustration the work is admirable and may be recommended to anyone desiring a readable, modern and compact work introductory to the literature of geology.

F. L. RANSOME.

SCIENTIFIC NOTES AND NEWS[1]

MR. SAMUEL FRANKLIN EMMONS died at his home in Washington, D. C., on March 28.

The death of Mr. Emmons comes as an unexpected blow to economic geologists, for it has removed from that science not only a pioneer worker in ore deposits, but one who has done as much as any economic geologist, during a long and active life, to promote the progress and welfare of this branch of geologic science.

Mr. Emmons was within a day of his seventieth birthday at the time of his death. The editors of this journal feel with especial keenness the loss of this able worker, not only because of his activity as a writer, but because of the deep interest and vigorous assistance which he rendered them in their efforts to make the Journal effective and valuable. It is their intention to publish in a forthcoming issue a biography of Mr. Emmons and a statement of his work which will serve, in some measure, to express their gratitude for his help and their deep regret at his loss.

SAMUEL CALVIN, professor and head of the department of geology, State University of Iowa, and State Geologist of Iowa, died at Iowa City, April 17. He was seventy-one years of age and had been connected with the University of Iowa for thirty-seven years.

AT RECENT meetings of the Section of Geology and Mineralogy of the New York Academy of Sciences the following papers were read:

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

Mr. G. Sherburne Rogers: "Geology of the Cortlandt Series and its Emery Deposits."

Dr. A. A. Julien: "The Evidences from the Palisades on the Genesis of Antigorite."

Mr. D. D. Condit: "Observations on Volcanoes and Guatemala."

Dr. George F. Kunz: "The Finding of a Great Beryl at Marambaya."

Professor A. W. Grabau: "Classification of Seas and Lake Basins."

THE ANNUAL meeting of the Canadian Mining Institute was held in Quebec, March 1, 2 and 3. The following officers were elected by acclamation:

President, Dr. Frank D. Adams, Montreal, Quebec. *Vice-presidents,* Dr. A. E. Barlow, Montreal, Quebec; Mr. T. Cantley, New Glasgow, N. S. *Councillors,* Dr. J. Austen Bancroft, Montreal, Quebec; Mr. R. W. Brock, Ottawa, Ontario; Mr. Arthur A. Cole, Cobalt, Ontario; Mr. E. T. Corkill, Toronto, Ontario; Mr. Theo. Dennis, Quebec, Quebec; Mr. John Donelly, Kingston, Ontario; Mr. E. Dulieux, Montreal, Quebec; Mr. F. W. Gray, Clace Bay, N. S.; Mr. G. E. Silvester, Copper Cliff, Ontario; Mr. J. B. Tyrrell, Toronto, Ontario.

THE PRESENT areas of public land withdrawn under their respective classes are:

	Acres
Coal	80,007.688
Oil and gas	3,796.572
Water power	1,403.054
Phosphate	2,548,145

AT THE twelfth annual meeting of The Geological Society of America, Cordilleran Section, held at the University of California, Berkeley, California, the following papers were read:

Arthur S. Eakle: "Neocolemanite, A Variety of Colemanite, and Howlite from Lang, Los Angeles County, California."

Arthur S. Eakle: "The Mineral Associations at Tonopah, Nevada."

Austin F. Rogers: "Orthoclase as a Vein Mineral."

C. H. Hitchcock: "The Tertiary Deposits of Oahu."

H. F. Reid: "A Note on Mountain-producing Forces."

Andrew C. Lawson: "On Fanglomerate, a Detrital Rock at Battle Mountain, Nevada."

J. C. Merriam: "Correlation of the Tertiary Deposits in the Pacific Coast and Basin Regions of North America."

J. C. Merriam: "Suggestions as to Definitions of Terms used in Designating Units of Geological Classification."

George D. Louderback: "Some General Features of the Miocene of the Southern Coast Range Region of California."

H. F. Reid: "The Nomenclature of Faults."

Oscar H. Hershy: "Some Tertiary and Quaternary Geology of Western Montana, Northern Idaho and Eastern Washington."

Andrew C. Lawson: "A Section of the Shinarump."

C. A. FISHER, of the firm of Arnold & Fisher, Denver, Col., returned the middle of March from a six weeks' trip to Paris, Berlin and Hamburg.

F. B. VANHORN, of the United States Geological Survey, spent several weeks in February and March in Florida and South Carolina investigating the present status of the phosphate industry, and in April was in Tennessee on the same business.

J. C. BRANNER will spend the coming summer in the geologic and biologic investigation of the northeast coast of Brazil. He will be accompanied by Professors MacFarland and Heath, of Stanford University.

ROBERT ANDERSON is spending the month of April in the Gulf Coast oil fields of Mexico.

N. C. GROVER, formerly Acting Chief Hydrographer of the U. S. Geological Survey and more recently consulting engineer for J. G. White & Co. of New York, was on March 1 appointed chief engineer of the Land Classification Board of the U. S. Geological Survey. His duties will be to pass upon railroad and irrigation matters and water-power site examinations and withdrawals.

F. L. RANSOME returned to Washington recently after spending four months of the past winter investigating the copper districts in the Globe and Ray quadrangles, Arizona. He also made a supplementary examination of the mines at Tombstone before the pumps were stopped. The detailed work at Globe, Ray, and Miami will be finished during the coming field season. Mr. Ransome has been assisted in this work by J. B. Umpleby.

AT THE meeting of the Geological Society of Washington held March 8 the Glacier National Park was described by M. R. Campbell and F. E. Matthes. Both papers were illustrated with stereopticon.

THE ALASKA coal-land leasing bill introduced in Congress by F. W. Mondell was defeated in the House by an overwhelming vote.

W. H. EMMONS, of the Department of Geology, Chicago University, is in the Geological Survey office at Washington for several weeks.

THE SUNDRY Civil bill contained the following items appropriating funds for the Bureau of Mines for the coming fiscal year: For salaries and general expenses, $54,000; for investigation of the causes of mine explosions, of methods of mining, of the use of explosives, and the prevention of accidents, $310,000; for analyses and tests of coals and other mineral fuels, $135,000.

THE FOLLOWING gentlemen will act as special lecturers in the course on economic geology at McGill University during the present session: R. W. Brock, Esq., M.A., director of the Geological Survey of Canada; Dr. J. D. Irving, professor of economic geology, Yale University, and O. E. LeRoy, Esq., M.Sc., of the Geological Survey of Canada.

THE FIELD Museum of Natural History announces in its thirty-fourth free lecture course the following subjects of interest to geologists:

March 4, "Precious Stones, how they are Found and Manipulated," Dr. George F. Kunz, New York City.

March 11, "The Glacial History of the Great Lakes," Professor Frank Carney, Denison University, Granville, Ohio.

April 22, "Recent Discoveries of Petroleum in the United States and Mexico," Dr. David T. Day, U. S. Geological Survey, Washington, D. C.

THE AMOUNTS appropriated for the work of the United States Geological Survey for the fiscal year ending June 30, 1912, include an item of $40,000 "for chemical and physical researches relating to the geology of the United States, including researches with a view of determining geological conditions favorable to the presence of potash salts." It is understood that one-half of this appropriation will be devoted to the potash exploration. Dr. C. W. Hayes, of the Geological Survey, was in Utah early in March, examining deposits of alunite, a hydrous sulphate of aluminum and potassium, as a possible source of potash.

MOST OF the appropriations for the work of the United States Geological Survey are included in the great Government supply bill known as "An act making appropriations for sundry civil expenses of the Government," popularly called the "sundry civil bill." The bill for the fiscal year closing June 30, 1912, contains appropriations for Survey work amounting to $1,205,520. The principal items are as follows:

Topographic surveys	$350,000
Geologic surveys	300,000
Mineral resources of the United States	75,000
Chemical and physical researches	40,000
Geological maps of the United States	110,000
Gaging streams, etc.	150,000
Surveying national forests	75,000

The bill also appropriates $165,000 for printing and binding survey reports, to be expended by the public printer.

In addition to these amounts the sum of $100,000 for surveys in Alaska was included in the urgent deficiency act, approved December 23, 1910, and the sum of $37,400 for rents was appropriated in the "legislative bill," making a grand total of about one and a half million dollars.